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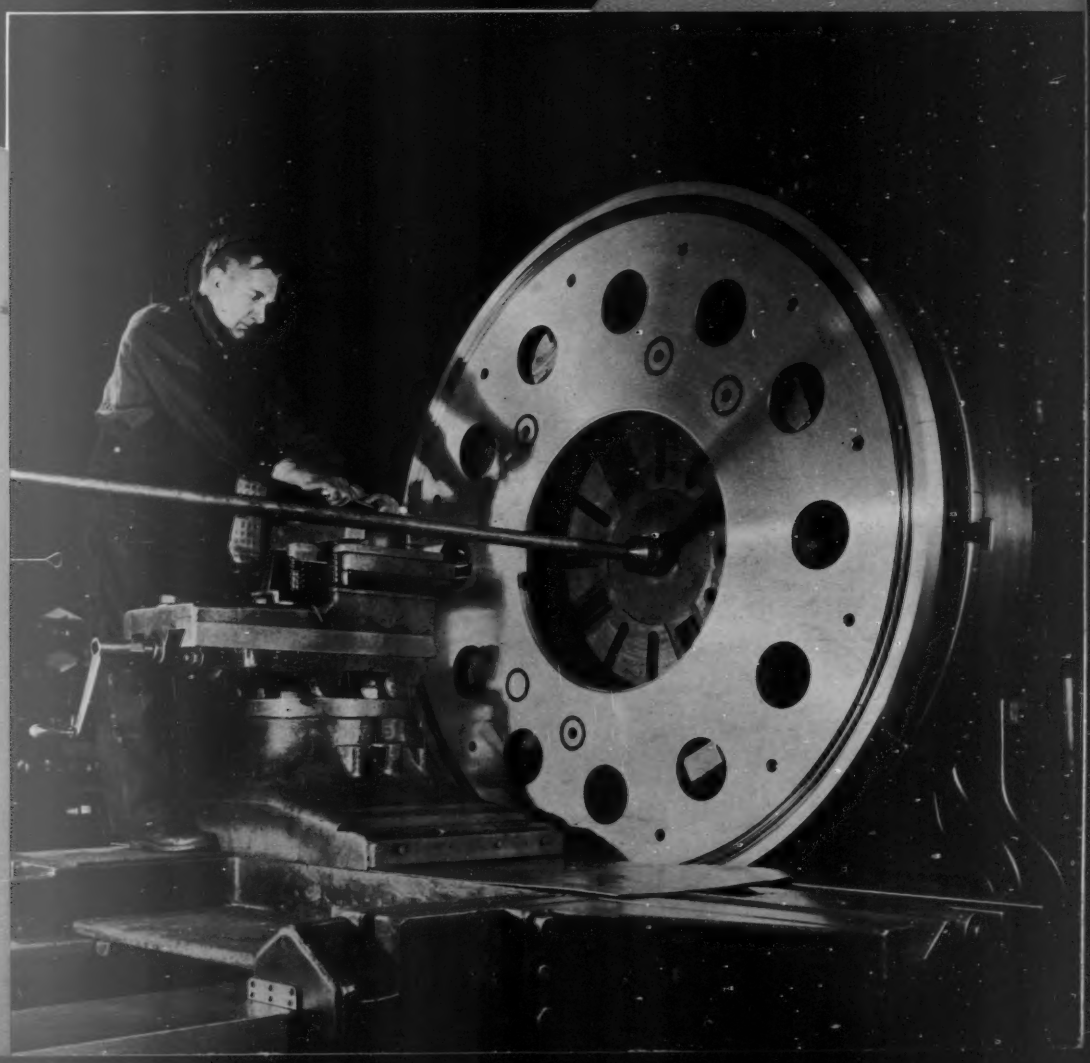
# ELECTRICAL REVIEW

June • 1938



Machining the anode plate for a 2500 kw mercury arc rectifier.

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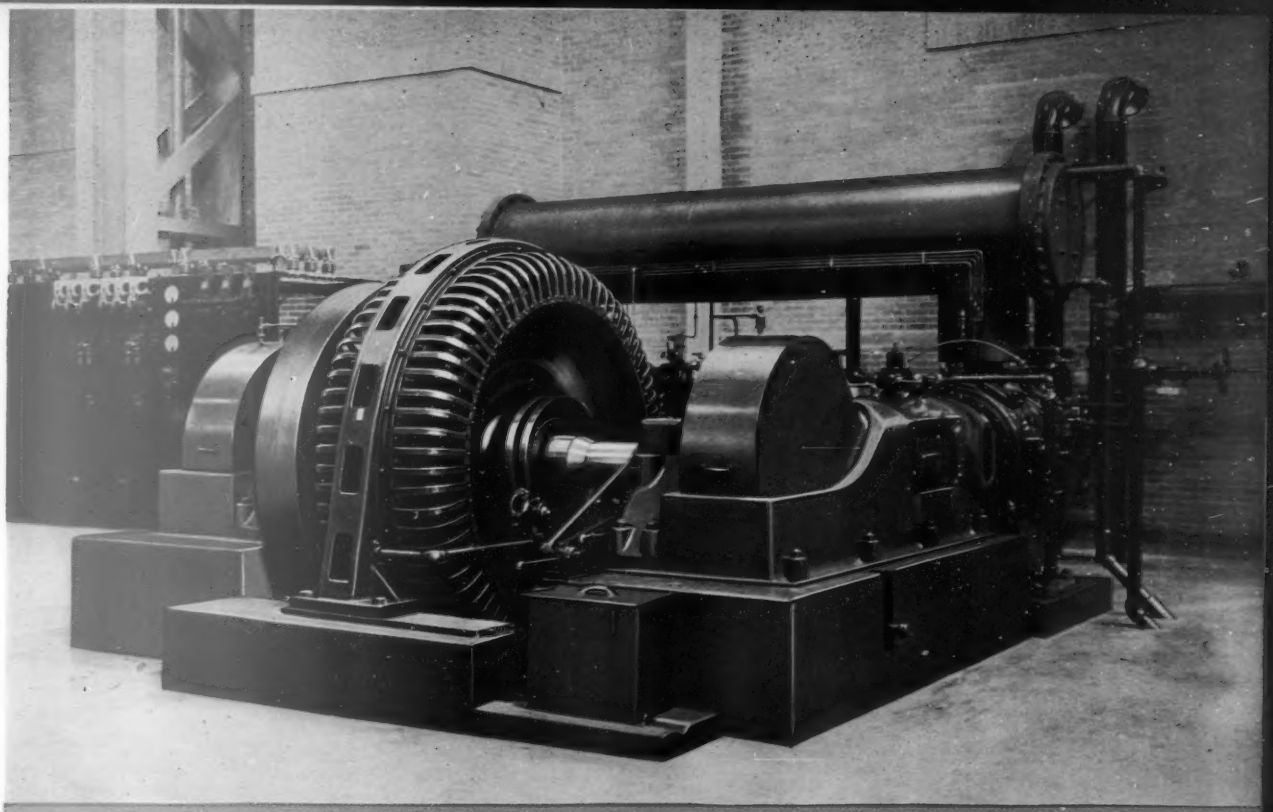


# FLYWHEELS FOR SYNCHRONOUS MOTORS

• F. K. Brainard

ELECTRICAL DEPARTMENT . . . ALLIS-CHALMERS MANUFACTURING CO.

Although synchronous motors are essentially constant-speed machines, additional flywheel effect is frequently used to advantage to reduce the variations of power and current drawn from the line which would otherwise result. If the load is a periodically pulsating one, such as that of a reciprocating pump or compressor, these variations would frequently be serious if suitable values of flywheel effect were not used. Excessive variations of current result in corresponding variations in voltage which may cause objectionable flickering of lamps supplied from the same circuit. Also in aggravated cases damage to the motor is possible.

The A. S. A. rule* covering this is as follows:

"When the driven load such as that of reciprocating type pumps, compressors, etc., requires a variable torque during each revolution, the combined installation shall have sufficient inertia in its rotating parts to limit the variations in motor armature current to a value not exceeding 66 per cent of full-load current.

"The basis of determining the variation shall be by oscillograph measurement and not by ammeter readings. A line shall be drawn on the oscillogram through the consecutive peaks of the current wave. The variation is the difference between the maximum and minimum ordinates of this envelope. This variation shall not exceed 66 per cent of the maximum value of the rated full-load current of the motor. (The maximum value of the motor armature current to be assumed as 1.41 times the rated full-load current.)"

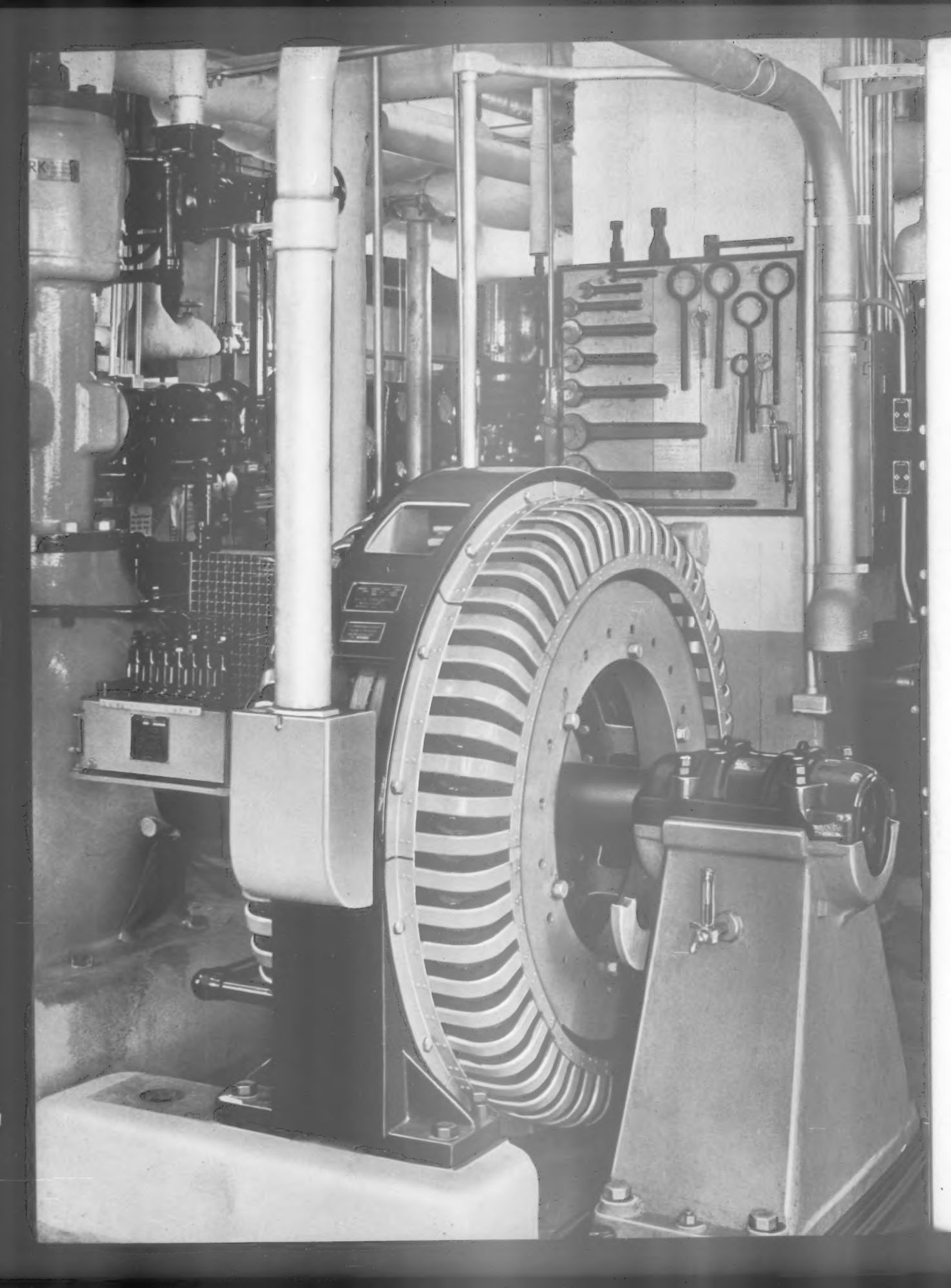
* See A. S. A. Standards—C-50-1936—paragraph 3.160.

ABOVE: Synchronous motor, 400 hp, 100% PF, 440 volt, 3 phase, 25 cycle, 214 rpm, driving compressor. Flywheel is at left. AT LEFT: Electrically welding a large casting for a steam turbine.

## • Partial resonance

The percentage variation in power and current drawn from the line will ordinarily be less than the percentage variation in torque which causes it, but this is not always the case, because there may be partial resonance between the frequency of certain impulses and the natural frequency of the unit on the power system.

Connecting a compressor with its flywheel to a power system by means of a synchronous motor is



analogous to connecting it to the prime mover in the power plant through gearing and a somewhat flexible line shaft. It runs at an average speed proportional to the speed of the prime mover but not necessarily constant at all times on account of the flexible connection, that is, there are momentary variations above and below the average value.

If the prime mover is very large compared with the compressor and flywheel, it is easy to see that the line shaft and flywheel in the mechanical analogy constitute a torsional pendulum which will oscillate at a definite frequency determined by the moment of inertia of the flywheel and the stiffness of the line shaft. Then if the frequency of certain impulses of the compressor is nearly equal to this natural frequency, partial resonance will occur and produce violent oscillations. In this case the variations in torque in the line shaft will be much greater than the variations in torque of the compressor. If these oscillations are very violent, the line shaft in the mechanical analogy might break, which corresponds to the synchronous motor dropping out of step. The stiffness of the shaft is analogous to $P_r$, the torque per radian of the synchronous motor.

The A. S. A. formula for natural frequency* of a synchronous machine on a very large system is:

$$F = \frac{35200}{\text{rpm}} \sqrt{\frac{P_r \times f}{WR^2}} \qquad (1)$$

The National Electrical Manufacturers' Association has adopted what they call "compressor factor" for use in determining the flywheel effect necessary for various types of compressors. It is designated by the letter "C" and is defined as follows:

$$C = \frac{0.746 \times WR^2 \times (\text{rpm})^4}{P_r \times f \times 10^8} \qquad (2)$$

It is a criterion for the comparison of the flywheel effects of various units. For a tangential effort curve of a GIVEN SHAPE the power pulsation expressed as a percentage of the average is practically a function of C only. Thus it is possible to determine values of C necessary to limit the power pulsation to the desired value if the tangential effort curve is known.

A great deal of work has been done on this subject, and values of C corresponding to 66 per cent pulsation have been adopted for the various types of compressors having the various methods of unloading.** Then, by substituting the values of C corresponding to the compressor under consideration in equation (4) below, the limiting values of flywheel effect can be obtained.

The definition of "C" given in Equation (2) does not indicate its character very well, since many of the quantities in Equation (2) do not depend upon the compressor at all. If Equation (1) is solved for $WR^2$ and this value substituted in Equation (2), it becomes much clearer. We then obtain:

$$C = 9.25 \left(\frac{\text{rpm}}{F}\right)^2 \qquad (3)$$

Even this is not self-evident since the compressor alone does not have a natural frequency. However, by specifying limiting values of C, we limit the ratios of speed to natural frequency which may be used, and so limit the ratios of electrical power variation to torque variation for each harmonic in the torque curve of the compressor. This is true because this last ratio depends principally upon the ratio of speed to natural frequency, the damping of the amortisseur winding of the motor not being so very important when operating well away from resonance, as is ordinarily the case. Thus we limit the magnitude of each harmonic in the resulting curve of power or current input, and by choosing suitable values of C, it is possible to keep the power or current pulsations within the desired limits.

For example, consider a horizontal duplex double-acting compressor with cranks at 90°. This compressor will have an appreciable unbalanced impulse occurring once a revolution resulting mainly from the angularity of the connecting rods; there will be no impulse occurring twice a revolution since whatever is produced by one cylinder will be neutralized by the other; there will be a small impulse three times a revolution; and there will be a large impulse four times a revolution resulting from the four compression periods. Thus the impulses with which resonance must be avoided by a wide margin are those corresponding to the speed of the unit, and four times the speed of the unit. Three times the speed of the unit should also be avoided but not necessarily by as wide a margin. From Equation (3), these correspond to the following values of C to be avoided, 9.25, 1.03, 0.58. The N. E. M. A. standard for this application is C = 2.0 to 6.0, or 12.0 and higher, which avoids resonance with the critical harmonics by a wide margin.

Solving Equation (2) for $WR^2$ gives the following convenient expression:

$$WR^2 = \frac{1.34\ P_r\ f\ C}{\left(\frac{\text{rpm}}{100}\right)^4} \qquad (4)$$

From this it is seen that the flywheel effect for a given type of compressor varies inversely as the fourth power of the speed and directly as the compressor factor, the frequency of the system, and $P_r$. Since $P_r$ varies almost directly with the rated output of the motor, the $WR^2$ will also. Accordingly the relative amounts of flywheel effect required by various types of compressors are directly proportional to the permissible values of C. Frequently a judicious modification of the design of the compressor will make a material difference in the values of C which can be used.

### Symbols

$P_r$ = Synchronizing power in kilowatts per electrical radian as defined in A. S. A. rules.
$WR^2$ = Flywheel effect of unit (in pounds feet squared, i. e., pounds weight multiplied by the radius of gyration in feet squared).
f = Frequency of the system in cycles per second.
F = Natural frequency of the unit on an infinite system in cycles per minute.
rpm = Rated speed in revolutions per minute.

* See A. S. A. Standards—C-50-1936—paragraph 3.161.
** See A. S. A. Standards—C-50-1936—appendix VI.

AT LEFT: Synchronous motor, 150 hp, 208 volt, 3 phase, 60 cycle, 277 rpm, driving ammonia compressor. Note that a ballast ring has been added to give the necessary flywheel effect.

# OPERATION AND MAINTENANCE OF MERCURY ARC RECTIFIERS

• R. O. Nixon, Superintendent of Power
PHILADELPHIA RAPID TRANSIT CO....PHILADELPHIA, PA.

• The commercial application of steel tank mercury arc rectifiers for interurban street car service began in 1915 with an installation made in Switzerland. The first application for similar service in the United States was made in 1924 and comprised one 500 kw unit. During the five-year period — 1924 to 1929 — 160,000 kw of rectifiers were installed for American electric railway service. The application of rectifiers for electro-chemical purposes and for other important power applications may exceed the service for electric railways in the future; however, the development of the steel tank mercury arc rectifier was advanced by the experience gained in railway operation.

With ten years' experience in the United States, users of steel tank mercury arc rectifiers are familiar with the pioneering work and the rapid improvement in the design, material, and manufacture of rectifiers. Some of the shortcomings of the earlier rectifier installations and the steps taken by the manufacturers to correct these shortcomings may be interesting to other users of rectifiers and to companies seeking information on this subject before making commitments for replacements of other types of converting equipment as well as for new installations. Some companies have had from 25 to 40 years' experience with the development and operation of rotary converters, but few companies have had more than ten years' experience with rectifiers.

Acting upon a suggestion that a contribution on the subject of operation and maintenance of steel tank mercury arc rectifiers by the Philadelphia Rapid Transit Company would be of general interest, because this company was concerned with some of the pioneering development work, the author takes this opportunity to describe some early experiences.

## • Chronology of Philadelphia transportation

The introduction of the steel tank mercury arc rectifier in America has its place in the chronology of street railway development in this country. Some excerpts from the chronology of the City of Philadelphia and the Philadelphia Rapid Transit Company are as follows:

1792–1830—Turnpike toll roads established, several of which were later used for passenger railways in Philadelphia.

1858—Jan. 20. First horse cars in Philadelphia.

1860—Steam dummy line introduced in Philadelphia.

1883—Apr. 7. First mechanical cable line introduced in Philadelphia.

1886—Electric storage battery cars introduced in Philadelphia.

1892—Dec. 15. First electric trolley cars introduced in Philadelphia. Power supplied by 600 volt d-c generators with connection to reciprocating engines.

1896—600 volt electric storage battery substations constructed in Philadelphia to augment power supply from the 600 volt d-c engine-driven units.

1897—Jan. 15. Last horse car operated in Philadelphia.

1903—First a-c power station constructed in Philadelphia for street railway operation (25 cycle turbo-generators and 25 cycle rotary converter substations).

1907—Mar. 4. First section of high speed line in Philadelphia — Market Street Subway-Elevated — put into operation. Power supplied by 25 cycle turbo-generators and 25 cycle rotary converter substations.

1910—Nov. First 60 cycle rotary operated in Philadelphia in connection with street railway.

1927—First steel tank mercury arc rectifiers operated for street railway in Philadelphia. Additional rectifiers put into service in the following years: 1928, 1930, 1932, 1936, and 1937.

## • Early rectifier installations

The Philadelphia Rapid Transit Company installed its first steel tank mercury arc rectifier for street railway work in 1927. This installation consisted of two 500 kw, 600 volt d-c rectifiers operated from three-phase, 60 cycle power. Additional rectifiers have been added to the system during the last ten years in connection with the operation of the company's own lines as well as in connection with operation of high speed lines leased and operated by the company. At the end of 1937 our company was operating 13 rectifiers with a combined nominal rated capacity of 23,000 kw. Three additional rectifiers are on order — two 3000 kw and one 1000 kw — which will bring the installed capacity up to 16 rectifiers and 30,000 kw.

AT LEFT: Delaware River Bridge High Speed Line, an important connecting link between Philadelphia, Pa., and Camden, N. J. 100,000 people cross this two and three-quarter mile span daily.

As the company's converting equipment was confined to 25 and 60 cycle rotaries up to 1927 with the full expectation of making replacements and additions of the same type, it is obvious that there must have been important reasons to try out rectifiers as early as 1927 even though it entailed some pioneering. We arrived at our decision to try out steel tank mercury arc rectifiers in connection with the design of a new substation to be used as a voltage regulator for one of our heavily loaded suburban street car lines. We desired quietness, as the substation was to be operated in a residential neighborhood, and we also desired to be free of 60 cycle rotary converter flashovers in an unattended substation. Prior to 1927 we had begun gradually to change from 25 to 60 cycle power, substituting 60 cycle rotaries for 25 cycle rotaries; and we found commutator flashovers becoming more recurrent with the 60 cycle rotaries.

We were impressed by the overload and short circuit characteristics of rectifiers as well as their quietness, which are two outstanding desirable features of rectifiers.

Another factor entering into our decision to try out rectifiers for street railway service was anticipated early abandonment of one of our combination 25 cycle turbo-generator and 25 cycle rotary converter substations supplying power to the same district wherein we were planning to install our first fully automatic 60 cycle substation. As the steel tank mercury arc rectifier had become available at the time we were trying to decide between manual or automatic operation for these two new substations for the district, we decided in favor of rectifiers and automatic operation.

The most recent rectifiers acquired by the company have been in operation since May, 1936. They were installed by the Delaware River Joint Commission in connection with the electrification of the Delaware River Bridge High Speed Line, which connects the City of Philadelphia, Pennsylvania, and the City of Camden, New Jersey. The Philadelphia Rapid Transit Company operates this line under lease. The rapid development of rectifiers is exemplified by comparing the operation and maintenance of our earlier types of rectifiers with this installation. To mention some of the difficulties with our first rectifiers will be interesting, as it will show the trend in development made by manufacturers from experience gained in the operation of rectifiers in electric railway service. These difficulties were, undoubtedly, common to all rectifiers in similar service during the period 1924 to 1934.

## • Difficulties with early rectifiers

Among the chief difficulties we experienced were the following: frequent arc-backs or backfires requiring from a few minutes to over an hour to restore proper vacuum so that the rectifier could be returned to service; difficulty in picking up load, particularly when a rectifier was first connected to the power supply; vacuum leaks due to deterioration of welds. These difficulties required frequent seepage tests which were usually followed by bake-out, necessitating a temporary shutdown of the rectifier.

The correction of these faults is linked with many improvements in the internal design of the vacuum chamber, in material free from gaseous content, and in greatly improved evacuating pumps. The installation of excitation anodes and improvement in ignition equipment were major developments. Vacuum leaks due to deterioration of welds were overcome by improved methods of welding with atomic hydrogen.

A large part of our troubles with rectifiers of earlier design was caused by corrosion.

The quality of water for cooling rectifiers is of paramount importance when using direct cooling. Direct cooling was used with the first rectifier installations. In this system the cooling water simply flows through the rectifier jackets and then is discharged to the drain. Since there is a continuous flow of water in the direct cooling system, the metal surfaces of the tank assembly are exposed to maximum corrosion, usually accompanied by extensive and severe pitting. This pitting if unchecked would soon result in destruction of the rectifier. Deep corrosive pitting results in a spongy condition of the metal. This interferes with maintenance of vacuum even before complete penetration of the metal results. Consequently seepage occurs, which places extra duty on the vacuum pumps and sometimes makes it necessary to bake out or de-gas the rectifier. The subject of corrosion of steel tank rectifiers has been given a great deal of attention in articles on the subject. Users of the early rectifiers are entirely familiar with rectifier corrosion. Others interested in this subject from the standpoint of historical development of the rectifier will find many articles available on the subject.

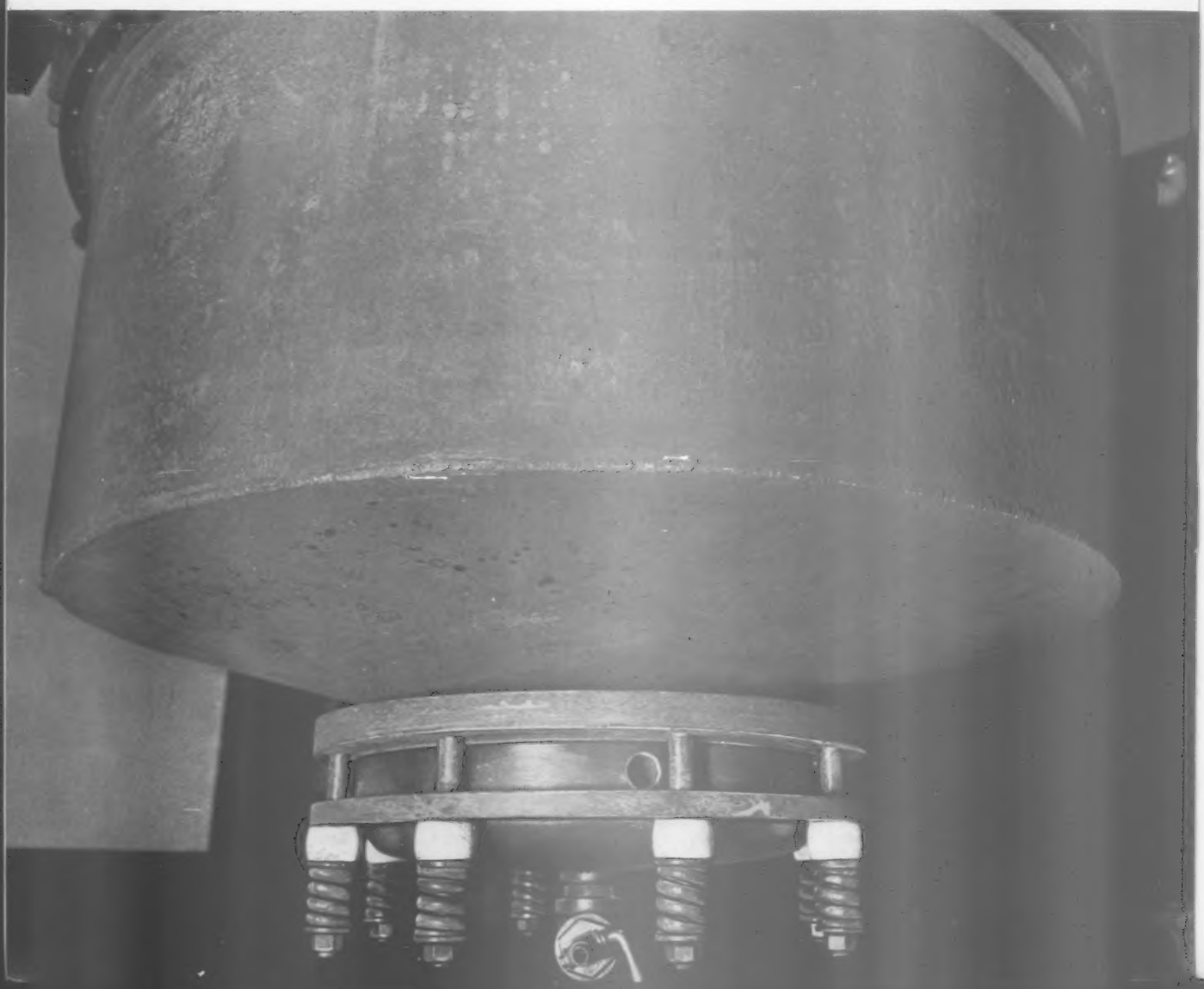


FIGURE 1: Severe corrosion of a rectifier cooled with running tap water, showing conditions after two years. The No. 2 rectifier of Pine Substation, Philadelphia Rapid Transit Company.

## • Sodium dichromate as a corrosion inhibitor

Rectifiers must be safeguarded from electrolysis due to current leakage through the water cooling system. Our rectifiers operate at over 600 volts potential to ground. Measurement of leakage current to ground on our rectifiers cooled by the direct cooling system showed from two milliamperes to ten milliamperes maximum. With this amount of leakage current, electrolytic damage appears neg-

ligible, and apparently is confined to metal pipe connections which are easily and cheaply replaced.

About three years ago we began to experiment with sodium dichromate as a corrosion inhibitor in two rectifiers normally operated on a recirculating system with full potential between rectifier and storage tank. We began with the recommended amount, that is one-half of one per cent solution; however, difficulties with arc pickup after zero load were experienced, owing to excessive ground leakage currents. We therefore reduced the concentration to approximately one-fourth of one per cent solution and doubled the length of hose connections to overcome this operating difficulty.

The concentration of the dichromate solution is frequently tested, and we add additional dichromate as required. Each year we flush out the entire system and then refill it with fresh dichromate solution. Water corrosion of these rectifiers appears to have been effectively checked by the use of sodium dichromate solution as a corrosion inhibitor.

## • The indirect cooling system

After five years' experience with the operation and maintenance of rectifiers during the period 1927-1932, we had become uncertain about making further investments in rectifiers until their development had become more stabilized. In fact, we selected 60 cycle rotaries instead of rectifiers for one substation which we changed from 25 to 60 cycles in 1932. Our main skepticism with respect to rectifiers was due to trouble experienced from water corrosion. We felt that the life expectancy of rectifiers was too uncertain to make further commitments at the time. We even gave serious consideration to the installation of slow-speed 60 cycle rotaries for use in residential districts where quietness was a requisite. Close cooperation between the users of rectifiers and manufacturers of rectifiers, particularly with respect to trouble experienced from water corrosion, brought about the indirect cooling system with water-to-water heat exchanger. Dosage of the recirculating water with sodium dichromate was also recommended by manufacturers for added protection from corrosion.

The indirect cooling system with the water-to-water heat exchanger has the disadvantage of adding additional auxiliary equipment to the rectifier but has reduced corrosion to a negligible factor. In addition to corrosion inhibition, the water-to-water heat exchanger also makes it easier to maintain the rectifier within the optimum range of temperatures under variable load conditions, which improves the operating characteristics of the rectifier. Severe corrosion of a rectifier cooled with running tap water is shown in Fig. 1. The improvement due to the use of a heat exchanger is shown in Fig. 2. Fig. 1 shows conditions after two years, and Fig. 2 shows conditions after one and a half years. These were our only photographs available with comparable time exposure to corrosion.

The use of the indirect cooling system with water-to-water heat exchanger should effectively safeguard rectifiers from both corrosion and electrolysis. We are convinced of this after only eighteen months' experience with the indirect cooling system. The question of chemical dosage of the recirculating water for such a system depends upon local conditions. Up to the present we are operating the indirect cooling system on four rectifiers without the use of a chemical inhibitor in the recirculating water.

High vacuum mercury vapor pumps with indirect cooling also became available to eliminate corrosion. As these pumps require cooler water than the recirculating water cooling the rectifier, it had heretofore been necessary to employ direct cooling for them. That is, cooling water from the fresh water supply flowed directly through the cooling jackets of the mercury vapor pump and was then discharged to the drain. Non-corrosive high vacuum pumps are now available wherein the cooling water flows through a coil of copper tubing which is wound around and soldered to the cooling surfaces formerly exposed to direct contact with the cooling water. This method of cooling is also now available for cooling the rectifier tanks as well as for cooling the high vacuum pipe and can be used in conjunction with a heat exchanger if the retention of the heat exchanger is desirable to regulate closely the temperature gradient of the rectifier water jackets.

These improvements in freeing the steel tank mercury arc rectifier from the ravages of corrosion so that it can now be considered a negligible factor, together with other improvements in general design, restored our confidence in rectifiers.

## • Rectifier quietness and interphase transformer noise

A feature favoring rectifiers, mentioned earlier in this article, was quietness in operation. This is true in so far as the rectifier itself is concerned. There is, of course, some noise from the motorized equipment, but this noise is usually not objectionable even in a residential district. There is a noise, however, from most rectifier units which should be mentioned, as it may be entirely overlooked in installing rectifiers where quietness is essential. The noise emanates from the interphase transformer and varies in intensity with load swing. It is a comparatively high-pitched whining sound caused by triple harmonic currents which flow through the interphase transformer. This triple harmonic frequency noise is somewhat muffled when the interphase transformer is built within the main rectifier transformer, but it is always noticeable and is sometimes objectionable. This should be borne in mind when it is intended to install outdoor transformers or rectifiers in residential districts. It is the opinion of the writer that rectifier transformer equipment still needs improvement to remove noise which is objectionable for some applications.

FIGURE 2: Improved appearance of vacuum chamber of rectifier with water-to-water heat exchanger, after one and one-half years. No. 1 rectifier of Birch Substation, Philadelphia Rapid Transit Co.

The power factor of rectifiers (lagging component) will usually be found to vary between 92 per cent and 95 per cent over a large part of the load range. This may be important in connection with power contracts and also in loading a-c distribution networks supplying rectifiers. The power factor of rectifier equipment is not subject to adjustment during operation, as in the case of rotary converters. While fixed quantities of static condensers together with automatically controlled static condensers may be used, it may be more desirable to compensate for lagging power factor of rectifiers by the use of synchronous equipment. The rotary converter should not be lost sight of where it may be operated to advantage in conjunction with rectifiers for power factor correction.

## • Comparison of efficiencies

With regard to the overall efficiency of various types of converting equipment in service on our property we compared the efficiencies guaranteed by manufacturers for 25 and 60 cycle rotary converters with 60 cycle mercury arc rectifiers. We determined that the overall efficiency of our rectifiers at the usual operating ranges lies about midway between 25 cycle and 60 cycle rotaries wherein the 25 cycle rotaries rated highest. This midway point for rectifiers is approximately 94 per cent between half load and full load. Because of the fluctuating characteristics of railway load, it is difficult to evaluate in dollars the slight difference in efficiency between 25 and 60 cycle rotaries and 60 cycle rectifiers.

Since the wave shape of the current the rectifier draws from the a-c supply is somewhat distorted even though the voltage of the a-c source is sin-

usoidal, which may cause telephone interference under certain circumstances, it may be necessary to install a-c filters in some cases. The telephone company has investigated this matter occasionally in connection with all rectifiers in operation on our property from 1927 to the present time. While some telephone interference has been traced to our rectifiers, the magnitude of such interference has not necessitated installation of a-c filters. Incidentally, we might also mention that the telephone company has occasionally traced telephone interference to our 60 cycle rotary converters. Most of this telephone interference, however, was experienced on telephone lines which had not been entirely modernized.

## • Comparison of costs and outages

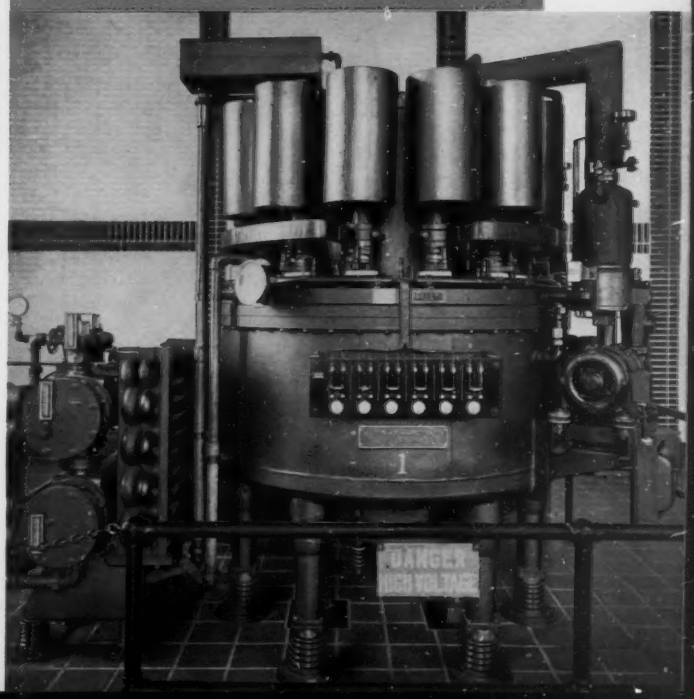
Maintenance costs for our earlier types of rectifiers exceeded maintenance costs for 25 and 60 cycle rotary converters. The rapid development of the rectifier reversed this condition, and the time lost because of outage of rectifiers for maintenance is now less than the time lost for outage of rotary converters. Rotary converters are free from auxiliary equipment, but this advantage is offset by occasional heavy maintenance due to commutator flashovers and armature failures. Rectifiers backfire or arc back occasionally but rarely suffer damage from this cause. The interruptions to service are usually momentary, of perhaps one-half minute duration. However, a slight flashover of a rotary converter commutator will require about one-half hour to recondition the rotary for further operation. The only maintenance necessitated by arc-backs of our rectifiers has been reconditioning oil in the oil circuit breakers. The condition of the oil is determined by dielectric test after 12 to 25 oil circuit breaker openings from arc-back, depending upon the oil capacity of the several types of oil circuit breakers used in connection with our rectifiers.

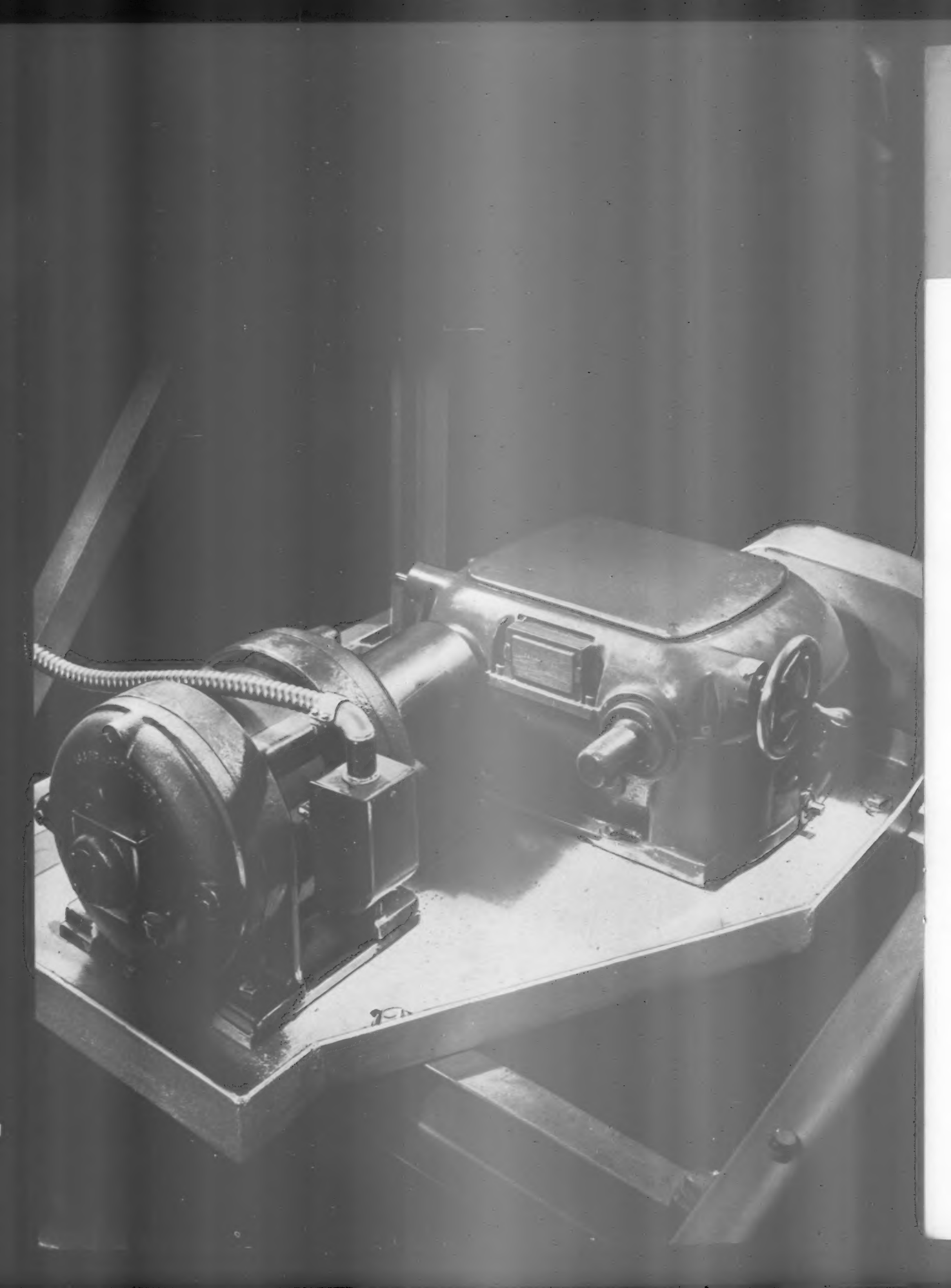
After 35 years' experience in operation and maintenance of 25 and 60 cycle rotary converters, we are now of the opinion that the steel tank mercury arc rectifier is more suitable for railway service than rotary converters. However, as previously mentioned in this article, the use of rotary converters should be given very careful consideration in connection with power factor correction where lagging component of rectifiers is objectionable in connection with power contracts and in loading a-c distribution networks. For several years we have satisfactorily operated 60 cycle rectifiers and 60 cycle rotaries in parallel by tying adjacent substations together through multiple d-c feeders. One advantage is that the rectifier is non-reversible (except during period of backfire), which favors rectifiers in preference to rotaries where there are violent fluctuations in load with intermittent zero or near zero load swings. Discriminate use of rotaries in conjunction with rectifiers should satisfactorily solve the problem of power factor where power factor regulation is important. Fixed quantities of static condensers, together with automatically controlled static condensers, may be used for power factor correction if the use of synchronous equipment is undesirable.

## • Protective application of grid control

Our experience with energized grids has been limited to grids energized for the purpose of facilitating the anodes in picking up the arc. We have definitely determined that these energized grids facilitate equalization of load between rectifiers operating in multiple on the same bus. Some of our rectifiers operating without energized grids have a tendency to shift load from one rectifier to the other with unstable division of load. Grid control is now available for voltage regulation and also for suppression of arc-back. This protective feature, suppression of arc-back, is of great importance in connection with the protection of the rectifier, the rectifier transformer, and particularly the rectifier oil circuit breaker. While this protective application of grid control has only been available for about a year and we have had no direct experience with it, we believe that design engineers should consider this protective feature very carefully, as it not only reduces the duty on oil circuit breakers but also effectively protects rectifiers and their transformers. It is possible that lighter duty oil circuit breakers will suffice for rectifiers equipped with grid arc-back suppressor control which otherwise would be inadequate. The design engineer can then weigh the additional cost of grid control for arc-back suppression against the saving effected in maintenance cost and in the use of lower capacity oil circuit breaker ratings.

BELOW: Installation of a 2000 kw, 625 volt rectifier tank with water-to-water heat exchanger. One of four similar units installed for the Delaware River Bridge High Speed Line.





# WHO INVENTED IT?

• Leo Teplow

PATENT ATTORNEY . . . ALLIS-CHALMERS MANUFACTURING CO.

The determination of paternity of children has involved a tremendous amount of research among medico-legal experts. Many and complex methods have been devised, involving laws of heredity as well as blood analysis, all of which, together with circumstantial evidence, must be considered.

Difficult as this problem may be, the determination of paternity of brain children is even more troublesome. One cannot resort to blood analysis of the invention, and hereditary characteristics are seldom recognizable.

## • "Build a better mousetrap"

The Ketch-A-Mouse Corporation manufactures an excellent, reliable mouse trap, but what with the onset of another depression and the active competition of Rattatorium, Inc., producers of de luxe streamlined mouse traps, the Ketch-A-Mouse Corporation is losing business. A new trap must be produced to attract the interest of a jaded public.

Mr. D. Zine is Chief Engineer of the Ketch-A-Mouse Corporation, while D. Velop is a subordinate — let us say a draftsman — in the employ of the same company. D. Zine lies awake nights in an effort to figure out a new and better mouse trap. He discusses his problem with his wife, his friends, his associates, his subordinates. It even affects his bridge.

Finally Mr. D. Zine calls his corps of draftsmen together and says: "This thing has gone on long enough! What do we have an engineering department for, and a million dollar appropriation, if you ———————— (profanity deleted.—Ed.) can't invent a better mouse trap than that bunch of so-called engineers at Rattatorium?! Let's go to work now, and work up a mouse trap that will rival the Pied Piper of Hamelin. Let's get a mouse trap that will attract mice and hold them. Two days on this; and I WANT RESULTS."

At the end of the second day Mr. D. Velop submits his inspiration. It is a novel and useful mouse trap, in which a piece of cheese is placed before a magnifying mirror. A mouse, on seeing the cheese, approaches it, but sees his reflection — a much bigger mouse, heading for the same cheese. Being a prudent mouse, he waits for the big mouse to go away, and starves to death.

AT LEFT: New variable-pitch speed changer, with multiple V-belt drive, operating conveyor chain in spray booth of paint shop. This unit has a ratio of 3¾ to 1, with maximum output at 3500 rpm.

A test on the company's proving and breeding grounds shows that the invention works like a charm. Working drawings are made up, sources of material contacted, and the company prepares to go into production on a mass basis. But hold! The president wants to know whether the company is free to make and sell the new "Mouse Boudoir." Mr. Pat Attorney is consulted and determines that the field is clear.

The next question is — can we protect it so that Rattatorium and our competitors cannot copy it? Mr. Pat Attorney is instructed to file a patent application on the new invention. One of his first questions is, "Who is the inventor?" Mr. D. Zine is not at all bashful. "I invented it. I told the boys to rig up a trap that would attract the mice and hold them. Here it is. Obviously it was my idea."

Mr. Pat Attorney is not so sure. "Did you tell the boys to arrange a mirror, particularly a magnifying mirror, behind the bait?" he asks. "No-o," admits Mr. D. Zine. "That was their job. I just told them what the problem was."

"Then you are not the inventor," says Mr. Pat Attorney. "The father of this brain child is the chap who conceived the idea of arranging a bait in front of a magnifying mirror." And so the patent application is finally filed in the name of D. Velop, who was the true originator of the revolutionary "Mouse Boudoir."

## • The inventor and the solution

With certain exceptions, the inventor is not the person who states the problem. The inventor is the man who hits upon the solution of the problem which the ordinary mechanic, the mythical "man skilled in the art to which the invention appertains," cannot solve. The inventor is not he who discovers that the house is wet because the roof leaks; the inventor is he who discovers a new and useful (and inventive) means to prevent the roof from leaking.

The general rule stated above — that the inventor is not the man who states the problem — is subject to certain exceptions. It may happen that the solution to a given problem is obvious once the problem is clearly understood, but the true problem is not obvious. Assume that it is not known why iron corrodes. A researcher comes to the conclusion that the corrosion of iron is due to the action of the oxygen in the air or in water. He concludes that if we could keep air and water out of direct contact with iron, we would prevent its corrosion. The solution is obvious — a coat of paint or other material impervious to air and water. In this case,

the true problem is unobvious, but once the problem is correctly stated the solution is obvious. The researcher who stated the problem (even though one of his subordinates completed the invention by actually painting iron with some impervious paint) is the inventor.

To put it in the stilted language of the courts: "Where a person has discovered a new and useful principle in a machine, manufacture, or composition of matter, he may employ other persons to assist in carrying out that principle, and if they, in the course of experiments arising from that employment, make discoveries ancillary to the plan and preconceived design of the employer, such suggested improvements are in general to be regarded as the property of the party who discovered the original principle, and they may be embodied in his patent as part of his invention."

To recapitulate, (1) the man who conceives improved means or method for accomplishing a result and shows how his conception may be adapted to use (or "reduced to practice") is the inventor. (2) Generally, the man who merely states a problem, the solution to which does not suggest itself to the average man skilled in the art has not made an invention. (The person who discovers such a solution may be an inventor, if the other requisites of invention are present.) (3) Where the true nature of the problem is not understood, the man who discovers the true problem, and employs others to work out the obvious solution or solutions, is an inventor.

## • Dangers of border-line cases

It is obvious that cases arise which are not easily classifiable in any category. Human relationships frequently defy attempts at classification. Once a classification has been set up, border-line cases will arise to bedevil the orderly soul who wants a place for everything and everything in its place. In such cases, the only thing to do is to consult the rules and to place each case in the category that comes closest to fitting, having in mind that, once a patent has been granted, the courts are loath to declare it invalid, unless the evidence is clear and convincing that the alleged inventor is not the true inventor.

Cases have arisen where an employer has obtained a patent in his own name, whereas the invention was actually made by an employee. If this can be shown, the patent will be declared invalid. Therefore it is to the interest of all concerned that the patent be filed in the name of the real inventor, whether he be the president of the company or an office boy. The parental pride of inventorship is so strong a factor that it is sometimes a difficult matter to determine the truth amidst conflicting claims. Not infrequently the patent attorney wishes he were a psychoanalyst so that he might determine which of two or more claimants is the real inventor.

Particularly difficult is it to determine the identity of the inventor when an employer or head of a department contests inventorship with a subordinate. It is all too common for a subordinate to have the feeling that every idea suggested by his superior was stolen from him. Equally obnoxious is an executive who unhesitatingly absorbs his subordinate's idea, makes some slight immaterial alteration, and sends it forth into the world as the product of his personal genius. Such procedure leads not only to invalid patents, but also to a great deal of friction within an organization. Moreover, such frauds are usually fully understood and regarded as such by the perpetrator's associates.

Perhaps the most difficult of all are cases of mixed paternity — where two or more persons are instrumental in contributing essential features of the invention, resulting in what is known as a "joint invention." But this is so fertile a field for discussion that we shall leave it for some future article.

BELOW: Statically balancing the largest adjustable blade runner in the United States, for 55,000 hp hydraulic turbines. Only 179 pounds were needed to balance the entire 120 tons.

# ENGINEERING FUNDAMENTALS

## CIRCUIT BREAKER RATINGS

Circuit breakers are essentially switching and protective devices used both to connect and disconnect load and to isolate defective circuits.

They are rated both in normal carrying capacity for continuous duty and in maximum carrying and interrupting capacity for emergency operation.

Each breaker carries a normal voltage rating, which represents the maximum system voltage to which the breaker may be subjected. The high potential test voltage is based on this voltage rating.

Each unit is also given a normal current rating, which represents the current which it can carry continuously without exceeding the standard temperature rise. As the heating is affected by the frequency of the circuit, this frequency is also made part of the rating. Circuit breakers for alternating-current circuits are normally given a current rating at a frequency of 60 cycles. Supplementary ratings are given for the same units at a frequency of 25 cycles, thus giving the necessary information for the two frequencies most commonly used in this country.

The above rating values constitute what might be called the normal rating of a circuit breaker. They represent circuit conditions to which the unit may be continuously subjected. They also represent information which is easily obtained.

With regard to "emergency" operation, the breaker ratings are concerned primarily with circuit phenomena of short duration. Four current ratings are given: (a) One-second or momentary carrying capacity. (b) Five-second carrying capacity. (c) Interrupting current at the circuit voltage under consideration, or kva interrupting capacity. (d) Maximum interrupting current.

With respect to (a), the one-second, or momentary, carrying capacity is the maximum current to which the unit should be subjected under any circumstances for any period of time, however short. The breaker is designed to withstand the mechanical forces resulting from the passage of currents of this value.

(b) represents a thermal limitation in most cases, and is of particular importance in the application of breakers which are not called upon to open circuits automatically. In these cases, a breaker ahead of the one under consideration is expected to clear the circuit in case of a fault. The five-second limitation of the non-automatic breaker might represent only a small overload on the larger back-up breaker, particularly where a number of branch circuits depend on one large automatic breaker for circuit protection.

(c) and (d) can be considered at the same time. Each breaker type carries an interrupting capacity rating in kva. The breaker can be applied at any voltage below its rated voltage. Thus a 15 kv three-phase breaker with a 250,000 kva interrupting capacity rating would be expected to interrupt approximately 10,000 amperes at 15,000 volts, but at 440 volts it would be expected to interrupt approximately 330,000 amperes, if no other limitation were set up.

To make a breaker good for operation at this tremendous current would obviously increase its cost to such an extent as to penalize unjustly each application at, or reasonably close to, its rated voltage. Consequently, each kva rating is supplemented by a maximum interrupting current rating, which actually sets up a definite minimum circuit voltage at which the breaker can be applied to its full rated kva interrupting capacity.

An additional limitation or reduction in interrupting capacity has to be considered in many cases. Because of the increasing use of automatic reclosing equipment in conjunction with circuit breakers, a unit may be called upon to interrupt a series of short circuits in rapid succession.

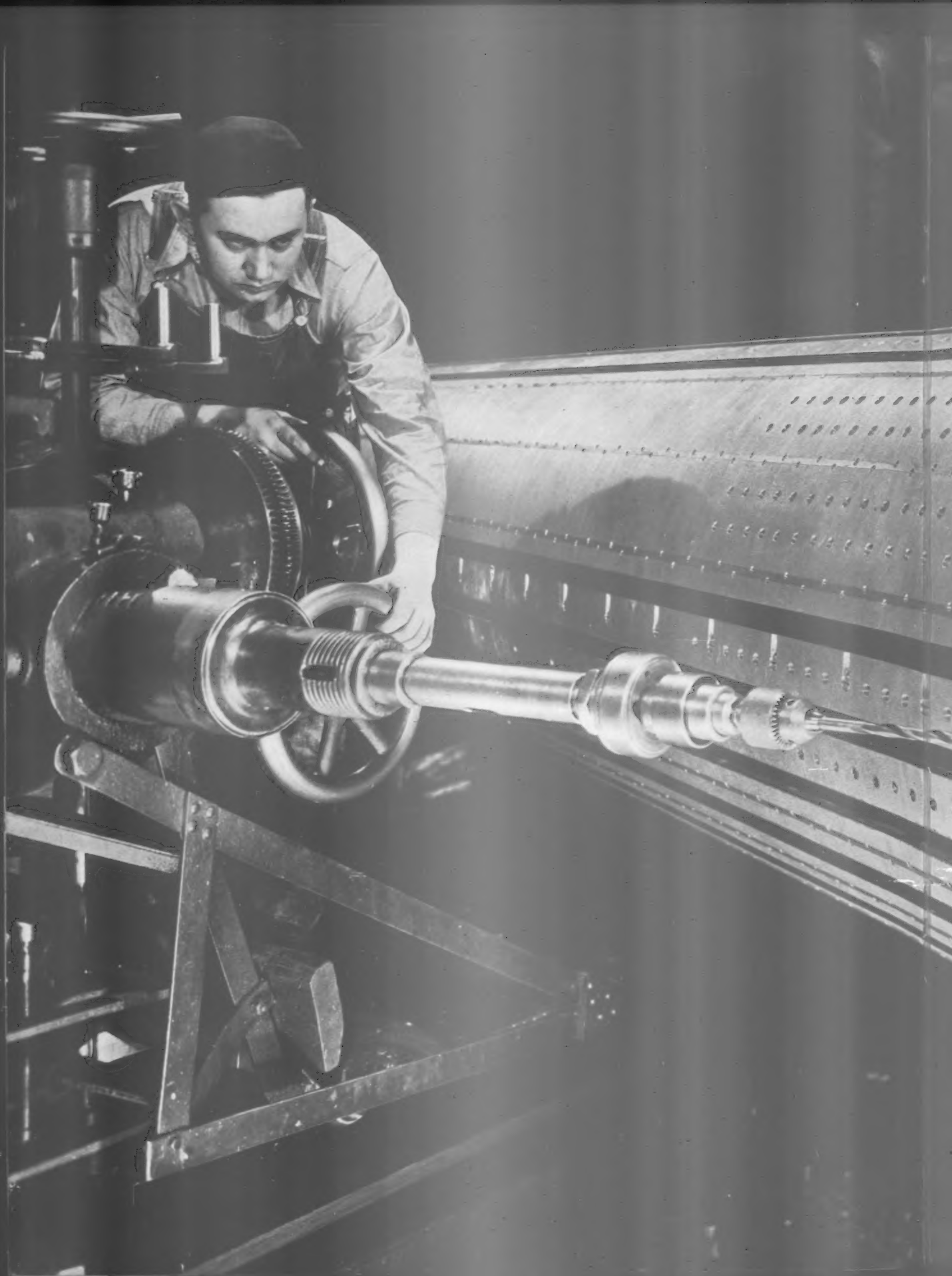
The standard rated interrupting capacities are based on two successive complete closing and opening operations with a 15-second interval between operations. Many systems now demand successive operation with no intentional delay between operations. Some systems require successive operations at varying time intervals, with immediate reclosure after the first interruption, and increasing time intervals between succeeding interruptions.

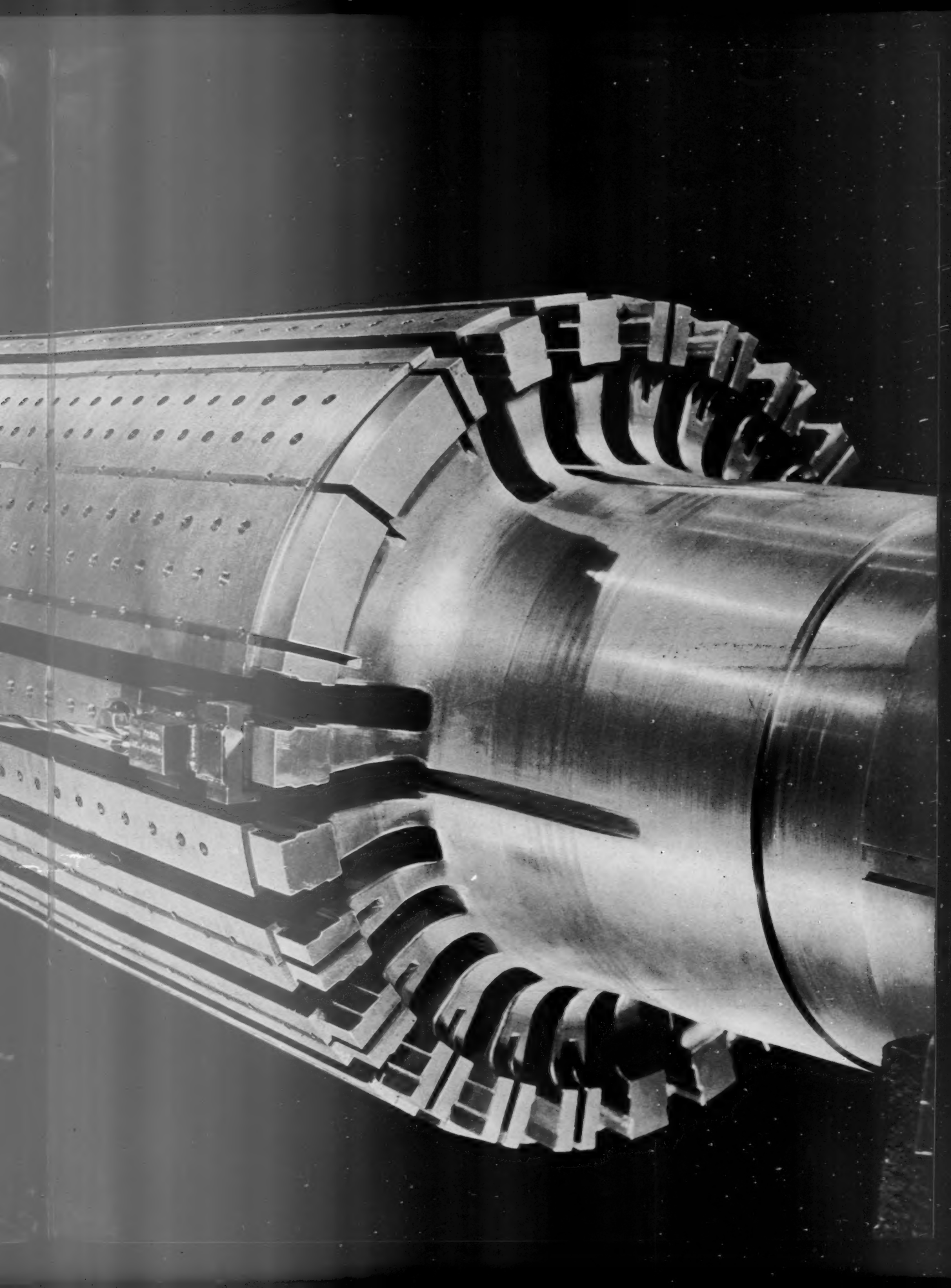
A derating table has been adopted by N. E. M. A., giving, in percentage of standard rating, the maximum interrupting capacity to which circuit breakers may be subjected, with various numbers of reclosures at various time intervals.

Any one of these various ratings may be the one which determines the breaker size for any specific application. It should always be remembered that circuit breaker ratings are maximum ratings and, with the exception of the normal current rating, should never be exceeded. The current rating may be exceeded for loads of short duration, such as the starting current of a motor.

In system layout, whether it be a large power system or a few feeders for an industrial plant, it is extremely important to consider the switching equipment along with the power machinery, and to make allowance for even more than expected expansion, before deciding on the operating voltage. It is often possible to pay a little extra money for higher voltage transformers and rotating machinery and thereby save more than the equivalent amount in primary conductors and switching equipment. The maximum interrupting current rating alone may force the use of, say, a 500,000 kva breaker on 2300 volt service, whereas a 250,000 kva unit would be suitable if the operating voltage were 6600 volts.

ON THE FOLLOWING PAGES: Careful and minutely accurate machine work is required to produce the slots for a rotor coil as well as the ducts and holes that are required for rotor ventilation.





# PROBLEMS IN THE DESIGN AND OPERATION OF A LARGE METROPOLITAN ELECTRIC SYSTEM*

• W. F. Sims, Chief Electrical Engineer
COMMONWEALTH EDISON COMPANY . . . CHICAGO, ILLINOIS

• Many of the problems in the utility industry are common to all systems regardless of size; others are more pronounced in the larger systems, but among the larger systems there is quite a variation in the types of problems. The problems in New York, Boston, Philadelphia, Detroit, and Chicago differ in many respects.

Then again the problems change — sometimes quite rapidly — from time to time as the system grows and as the art of distribution of power and of the design and manufacture of electrical equipment progresses. Further, the design of the system is a process that is carried on continually as the load grows and as conditions change. The problems of today in many cases are far different from those of a few years ago.

## • Influence of external factors

In general, the problems that have to be met are influenced by the history of the past development of the company and its policies and by the type and character of the system as it existed at any particular time. The topography of the area served has a very definite influence upon many of the problems. Contractual relations with adjoining utilities serving adjacent areas also have their effects. Local ordinances and regulations, such as city planning and zoning laws and restrictions on the use of overhead conductors, must likewise be taken into consideration, as well as the location of available generating station sites, etc.

Other important problems that are sometimes rather difficult to handle are those that are brought about by the type and character of new load. The obsolescence of equipment brings its problems into the picture, as it is necessary to keep the system up to date and avoid hazards that may grow with such obsolescence.

Those are all general statements serving as a background to what I am going to say.

## • Background of the Commonwealth Edison Co.

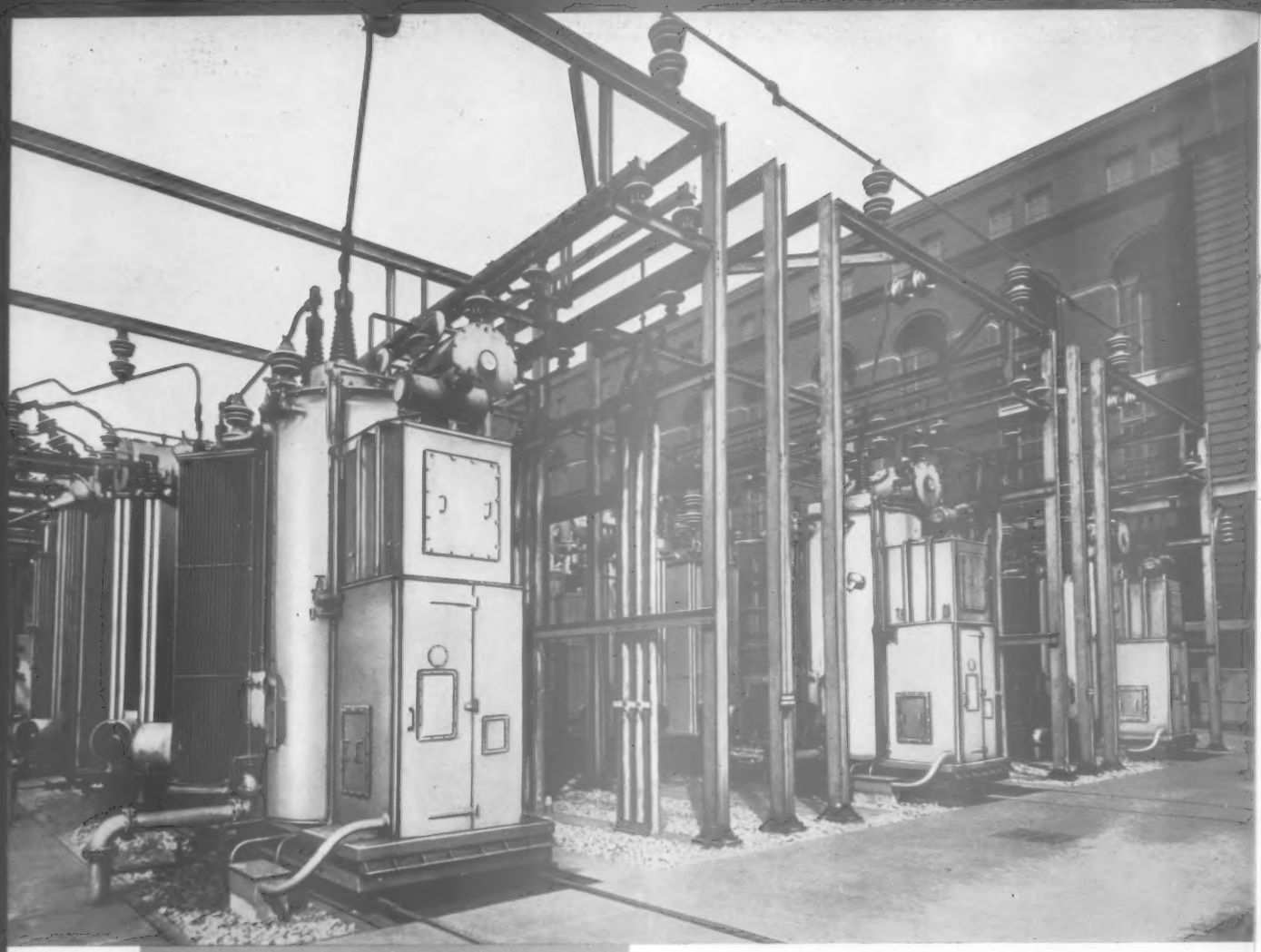
This subject probably may be best discussed by reference to the system with which I am most familiar—namely, that of the Commonwealth Edison Company in Chicago—and a brief history and description will indicate certain features which should convey a fairly good picture of that system.

The City of Chicago covers about 210 square miles, and that is the area in which the company operates. Originally the Chicago Edison Company was formed under a franchise covering about a dozen square miles in the Loop section and adjacent areas. That company was itself a consolidation of several isolated plants and one or two smaller companies. This area was developed as a direct-current, 3-wire system, at 110-220 volts, and was served by several small steam engine stations generating at 230 volts. The area outside that served by the Chicago Edison Company was originally served by a large number of smaller companies scattered throughout the area with quite a variation in voltages and frequencies, as well as in number of phases. These companies were acquired by the Commonwealth Electric Company, which was under the same management as the Chicago Edison Company, and which developed that territory by unifying the systems, standardizing on 60-cycle, 3-phase, 4-wire, 2300-volt distribution. These companies were merged in 1907 as the present Commonwealth Edison Company.

In 1901 the maximum load on the system was about 20,000 kw, which grew to over a million kw in 1929. Such growth brings many problems. In meeting this increase in load, between the years of 1920 and 1928, two complete power stations were built, each with six turbo-generators ranging in size from 30,000 to 100,000 kw, or a total of 600,000 kw. When we speak of the growth of the power stations and the addition of that capacity, we have only made a start, because unless that power can be taken to the market and disposed of, we have only the generating capacity to show for our investment. So along with that necessarily comes a very great increase in the transmission system, conduit and cable between the points of generation and the substations, and a very large development of the substations and the distribution system. Over a period of years the annual budgets for new construction ranged from 18 to 33 million dollars and averaged about 25 million a year. These dollar figures serve as a measure of the amount of work that had to be done.

The 66 kv system which interconnects the generating stations was not initiated until 1926. It began with the installation of four banks of transformers, each of 60,000 kva, at three locations, and with two 66 kv lines. Today there are 20 banks of transformers in six locations with an installed capacity of 1,300,000 kva and 126 circuit miles of 66 kv underground cable.

* Abstracted from a speech presented at the January 5, 1938, meeting of the Milwaukee Section. A. I. E. E.



ABOVE: Regulating transformers (in the foreground) for supplying 10% raise and 10% lower in a 66 kv, 100,000 kva circuit. Shown is the 66 kv terminal of a metropolitan electric system.

## • Load forecasting

Getting more specifically into the problems that are represented by the growth and operation of such a system, perhaps the basic problem from the point of view of the engineer responsible for providing the necessary facilities to meet the demand is load forecasting. Load forecasting has to be somewhat long ranged. It does not mean guessing at what the load will be next year and stopping there, because the larger projects take from two to three years from the date of authorization until the date of service, which means that we must try to have some idea of what the load will be several years ahead so that we may be able to determine whether we should start an expansion program now or later. Not only that, but we have to look further ahead in planning the initial installations so as to have some idea of what the ultimate growth of the stations will be and make provisions for that future growth.

All this comes back to some determination of what the load is going to be. The question may well be asked — how can we forecast load?

Load forecasting takes into consideration the history of the past growth of the system together with what information can be obtained about the development of various localities in the city, some idea of what the new business departments are doing in acquiring new load, and what the trends are in industry. In our company we start with the substations and try to determine what the load on each substation will probably be. Because the maximum demand on different substations frequently occurs at different times of the day, a diversity factor determined from experience is applied to obtain the load in each generating station zone. These forecasts are made each year for a five-year period and are revised not only annually but oftener, as occasion demands. Load forecasts are made not only for the Chicago company but for the entire interconnected system, because it is upon this information that the determination of the generating capacities required is made.

Load forecasting is one very definite and fundamental problem in the design of a metropolitan

utility. It is true that the problem is present to a greater or lesser extent in the smaller systems, but it becomes more acute and the solution more and more important as the system becomes larger and larger. A slight error in load forecasting on a small system does not involve a large investment of money. On a big system it would run into millions of dollars very rapidly.

## • Economic considerations difficult to solve

It is probable that the general impression is that the problems to be considered are largely technical, but the technical problems usually are not so difficult as certain other types of problems. I believe that the economic problems are probably the most difficult of solution, as so many economic considerations must be taken into account. A good many years ago a prominent utility executive made the statement that the job of the public utilities was to furnish the best possible service at the lowest possible cost commensurate with a fair return upon the money invested. That principle very clearly expresses the basic principle of utility regulation, but it brings with it many difficult problems.

The first thing is to make the most effective use of the capital invested in the business. That means that the design and layout of the system must be such as to be the most effective and require the least overall investment in stations, transmission lines, substations, etc. However, there is an opposing force working against this result — and that is, the design, not only of the individual stations or substations, but of the system itself, must be such that it will give the best assurance of regular dependable service with constant voltage and frequency.

There is a large amount of money invested in all utility properties for the sole purpose of making the service dependable and of high quality. It probably would be impossible for any company to make an estimate of just how much that money is in dollars or what percentage of the total investment, and right there is where the most difficult problems of design come in — to determine how far we should go to safeguard the service. In making a design for a new installation the engineers take into account the possibilities of troubles that might develop and endeavor to make provisions for preventing them. In so doing there is a tendency to give undue weight to some very remote possibilities, the protection against which might add an excessive amount to the cost of installation. Great care and the use of sound judgment must be applied in making such decisions. It is necessary to be constantly alert to see that we do not go too far and build an unnecessary degree of security at too high cost into the system.

## • Reserve equipment supply

Another factor from the economic point of view that enters into the design of the system is the consideration of the value and extent of reserve equipment to be supplied. We have adopted a policy on our system of setting up as a standard for generating reserve a generator capacity equal to the two largest units on the system, on the theory that, if the largest unit is out for any reason whatsoever at the time of peak load and the next larger unit gets into trouble, we will still have sufficient capacity to take care of the load.

Going farther out into the system, in the 12,000 volt transmission between stations and substations, each substation supply must be so designed that if any one line to a substation or interconnected group of substations is out for repairs or any other reason and a second line goes out, the remaining lines can carry the substation load within a reasonable limit of overload. In the same way within the substation, the firm capacity of the substation including an allowance for reasonable overload should not be less than the maximum load on that substation.

On a large system a particularly serious problem is the magnitude of short circuits, that is, the amount of energy that can be concentrated in a single fault. Practically all engineers in this line of work are very careful in system layouts to design the system in such a manner as to limit the magnitude of a fault that can occur anywhere on a system to a predetermined value. Those limits may vary in different systems. On our system we try to keep it within one million kva. The system has been designed to operate sectionalized, reactors are installed at strategic locations, and the system is so set up that a short circuit at any location should not be appreciably greater than one million kva.

## • Problems of system protection

The sectionalizing of the system also is quite valuable in limiting the trouble to only one portion of the system. And that leads to another problem — the problem of system protection: Where should relays be installed? How many? What kind? How should they operate? and so on. We protect our generators with balanced differential relays so that any trouble in the machine will immediately clear the generator and take it off the lines. In our newer switch houses at Calumet, Fisk, and Crawford stations and at the two distribution stations we have adopted the isolated phase form of construction. In this design of switch house, each of the three phases is in a separate room, and a neutral resistor is installed in the circuit so as to limit single phase to ground short circuits to a predetermined value. The probability of 3-phase short circuits thus becomes exceedingly remote, and if the single phase to ground short-circuit current is limited to a reasonable value, there should

be little trouble in procuring equipment and making installations that will withstand those short circuits.

In the isolated phase stations a form of bus protection, termed a "ground-fault bus," has been developed. It is simply an installation of large-sized copper bars sectionalized in much the same manner as the busses are sectionalized and paralleling all of the busses, to which are connected the insulator bases, disconnecting switch bases, oil circuit breaker tanks, current transformer supports, etc. These copper bars are connected to the station neutral bus through individual current transformers to which are connected multi-point instantaneous relays. These in turn operate the individual relays on the various circuit breakers so that if an arc to ground occurs, the current will flow through the fault bus to the current transformer which operates the proper relay, and the fault is cleared. One of our engineers, in attempting to explain this system to some non-technical visitors who did not readily understand, said, "Well, briefly then, this is an arrangement of copper bars, current transformers, and relays so connected that when a fault occurs the fault current commits suicide." We have yet to have an operation that was not exactly as designed, although we got into trouble in a few cases, because we had not then gone far enough in our design. As in any relay arrangement for system protection, it must be so designed that it will clear the faulted portion as quickly as possible, leaving the rest of the system normal. The extent of the system taken out of service by these relays should be such as to cause a minimum or no interruption of the service.

## • The a-c network analyzer

The calculation of circuit breaker interrupting duty on a large system is quite a task. We are now equipped to do that quite readily for the reason that some years ago we installed an alternating-current calculating board, also known as the a-c network analyzer. We were the first public utility to own such a board. On the board are set up in miniature the characteristics of the part of the system that we are studying, and by means of a small motor-generator set energy is supplied at 420 cycles. By reading the instruments and by the application of constants we can determine, with any given condition on the system, not only the short-circuit current at any location, but power flow, stability problems, and other problems of a like nature very much more rapidly and much more accurately than can be done by the ordinary mathematical methods. We have found this board to be invaluable, as it has simplified many of our problems by the readiness with which these problems can be solved and by the certainty we now have of the accuracy of the solution.

On the large systems the problem of mechanical strength of busses and other connections becomes very important because of the large concentration of energy that may occur at the time of short circuit. The mechanical stresses set up by busses at times become enormous. We and other utilities of our size have had to develop designs of busses and bus supports and to do a considerable amount of practical research in connection with materials and fittings in order to build our busses in such a manner that they will withstand any forces that may be brought about by reason of short circuit conditions. In earlier days there were a number of experiences with busses being ripped from their supports, insulator inserts being pulled out, and many other difficulties of a similar nature. Today such destructive results of short circuits are very rare.

## • Elimination of the chances of oil fires

The prevention of oil fires is one of the important problems that we have to consider. During the past ten or twelve years there has been a very rapid growth in the amount of large oil-filled equipment on the larger systems and also a large increase in the size of transformers, which has resulted in the accumulation of considerable quantities of oil in various installations. Because of the rapid development along this line, the seriousness of the problem was not fully realized until about seven or eight years ago. Since that time a great deal of study and work has been undertaken in connection with the prevention or reduction of oil fire hazards. Practically every utility in the country in recent years has spent large sums on its existing substations, as well as on its new installations to eliminate the chances of oil fires.

## • Substation rehabilitation

The rehabilitation of obsolete substations is another interesting problem. Most systems have substations that may date back 25, 30, or 35 years. On our own system, although the majority of substations is not anywhere near that old, we have a few that are approaching that age, and we have adopted a somewhat definite program of rehabilitation of those substations, one or two a year, so as to avoid the use of obsolete equipment on our system.

The principal problems in their reconstruction are brought about by the fact that the substations are filled with equipment, because they grew rapidly, and there is no more real estate available to extend the buildings. Yet service must be maintained, while the old equipment is being taken out and new equipment put in. The cost of rehabilitation is rather high.

## • Research on special equipment

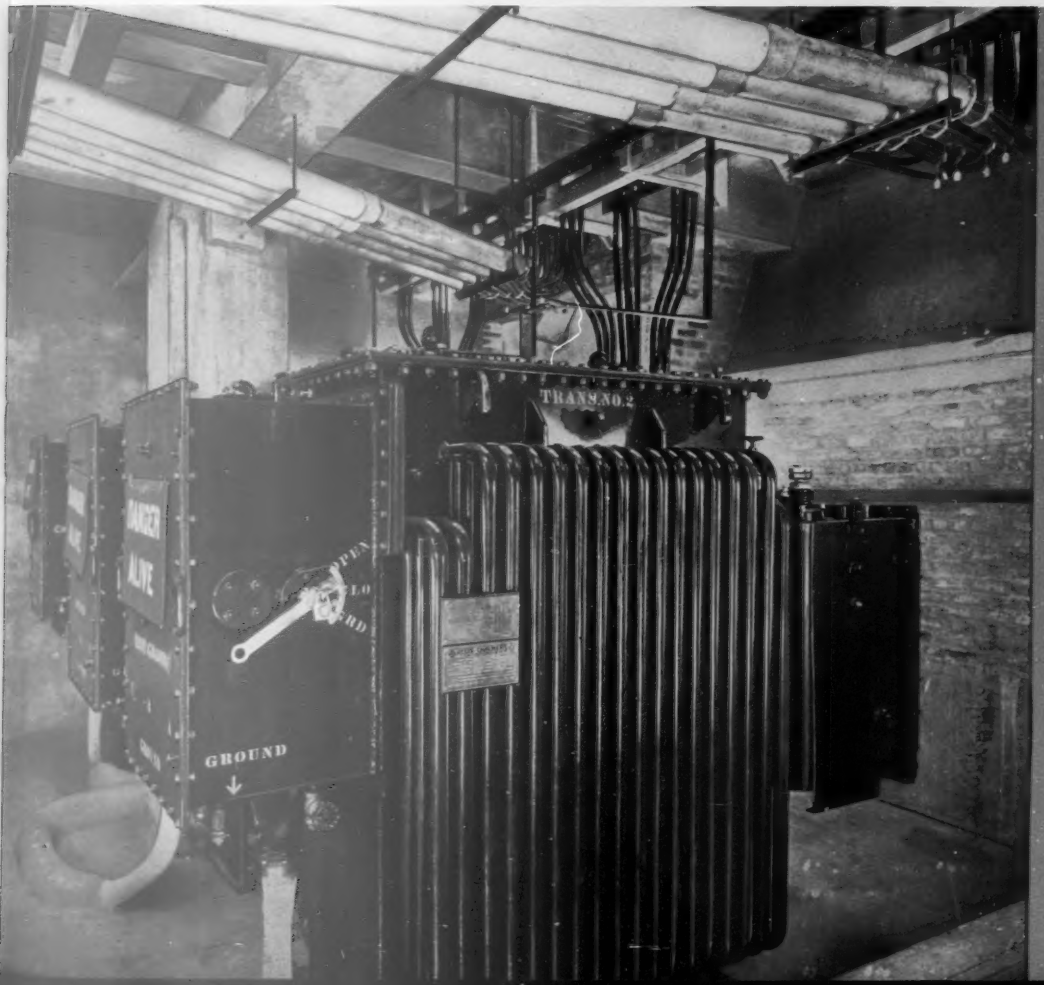
Another important problem for metropolitan utilities is the securing of suitable equipment to meet special conditions which arise from time to time and working with the manufacturers in the development of such equipment. That is a most interesting problem and is what might be called "practical research." In my opinion it is not desirable for a utility to set up a research laboratory and go in for pure research. That is a job for the manufacturers and the universities. But I do believe that it is the job of the utilities to work along the lines of practical applications of new developments and to cooperate fully in the work being done in the research laboratories of the universities.

In that line, the study of insulating materials has become quite important in tying in with the development of high voltage underground cable. Our own company has taken a rather prominent part in that development, and the high voltage underground cable of today is quite different from the cable of eight or ten years ago.

Electrolysis and corrosion problems are continually with us although we have them fairly well under control. We have a group of four or five capable engineers who have made special studies of these problems and are continuously working on them. They have developed some interesting and valuable information.

## • What to do with the d-c system

Another problem causing a great deal of serious consideration at the present time is in connection with our direct-current system. As I stated, the system of the Chicago Edison Company was originally developed on a direct-current basis. We have at the present time a direct-current load of about 175,000 kw which is in the downtown district. At the time it was developed the direct-current system was the best and most dependable system known. With all substations connected to a common network and backed up with storage batteries, it guaranteed a practical continuity of supply. It was not until rather recent years that transformers and other equipment associated with them had been so developed as to enable the utility to operate, maintain, and give equally dependable service on an a-c network. It has been found that the investment and operating costs are less for an a-c network system than for a d-c system. Naturally, with facilities for the better and lower cost system now available, it is not advisable to spend any more money than necessary in extending the d-c system. But the load continues to grow in that area. The existing substations are being loaded up more and more each year, and we have had to take steps to limit that growth. We have started work on the building of an a-c network in the downtown area and are cutting over to that system sufficient load each year to prevent further growth of the d-c load.




AT LEFT: Network transformers in the low tension system of a large metropolitan utility. These transformers are 500 kva. 12,000 volt primary to 208 volt secondary.

In the investment budget there must be allowances for providing network transformers in vaults with high tension and low tension cables. That is a problem that is going to grow and become more acute as years go by. The downtown stations are quite well loaded. In existing substations there are only two or three places where there is room for another machine. What to do with the d-c system is an absorbing problem. We must get the best out of the large investment, we must avoid any further increase in investment, and we must retire old equipment as it reaches the end of its useful life and be in a position to take on increasing loads on the new a-c system.

## • The cutover of Fisk Station

One of the specific problems we have had to meet was at Fisk Station, originally designed to house fourteen 5000 kw vertical turbines, or a total of 70,000 kw. It was first placed in service in 1903. Today it has ten 12,000 kw vertical units and four horizontal units to which has been added a topping turbine — a total capacity right now of 260,000 kw in a building area originally designed for 70,000 kw. There were two control galleries in the turbine room. It became necessary a few years ago to provide two large frequency changers to connect the 60-cycle system to the 25-cycle system in order to improve our operating conditions, and a temporary control center was put in for these machines. Then a new 60-cycle switch house was built, and its control wiring added to this center. In the meantime, the 66,000-volt terminal grew very rapidly, and the control wiring from that was also connected in with the temporary gallery. By that time the amount of equipment controlled from this temporary installation was greatly in excess of that originally intended and it became quite crowded. When it was decided to put in the new topping turbine it became necessary to install a new consolidated control gallery. A complete new control board for the entire station was installed in a new location and all the control circuits transferred to it from the old control boards.

In order to maintain service and to avoid any unnecessary outages it was necessary to lay out the cutover in steps and to coordinate the work of all the separate divisions of the engineering department (design, field engineering, and drafting) and the construction, operating, and testing departments. To carry on the work so that nothing was forgotten and to have all the departments work together as smoothly as an orchestra was a mighty interesting problem that was successfully worked out by the engineers responsible for the project.

## • Proper regulation of voltage

The question of voltage regulation on the distribution system is another nice problem. The Illinois Commerce Commission requires that the voltage on the system be checked once every three years and be kept within rather narrow specified limits. One of the sections of the engineering department does nothing else but go out with recording instruments over the entire system, checking up voltage conditions and transformer loadings. From the data thus secured the reinforcement of secondaries replacements of distribution transformers, and other work necessary to maintain proper regulation of voltage at the customers' premises is determined.

The question of load control is something else to be considered. Here we have a system of generating stations in the city interconnected with outside stations, the outside stations being much newer stations and consequently more efficient than the older stations. We have the problem of operating the system so that the lowest cost per kwhr is obtained consistent with the maximum reliability of service. Our operating men have the responsibility of solving that problem. They have worked out a system of schedules for individual station loads for various total system loads in such a manner that each station carries its proper proportion of reserve capacity and the overall kilowatt hour cost is the lowest possible under the most reliable conditions of system operation. The supervision of the loading of the various stations to insure the maintenance of these schedules is one of the principal duties of the load dispatcher.

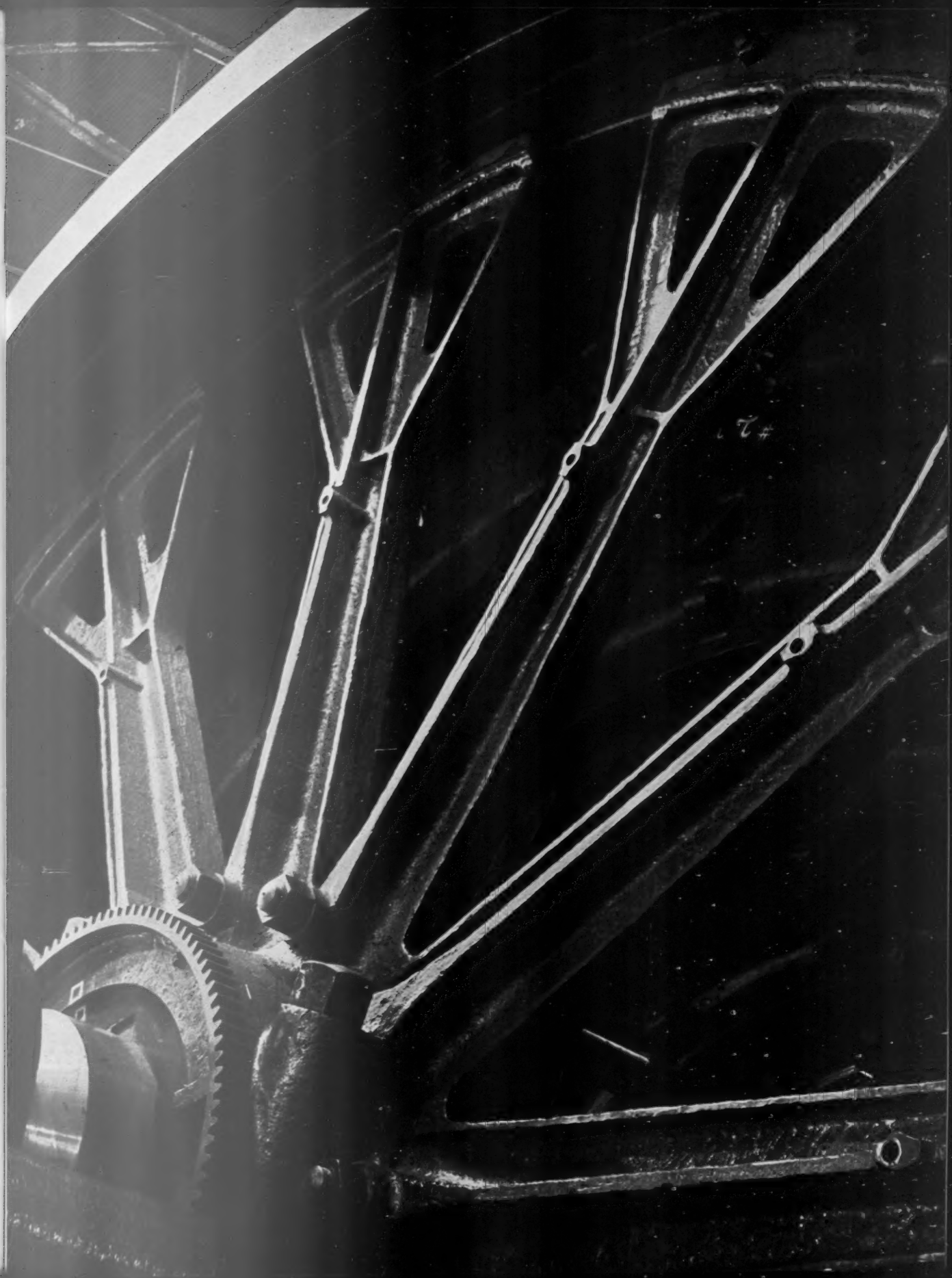
## • Emergency operation and overhaul

In cases of serious system disturbances caused by burnouts or other reasons, emergency operation is the big problem. It is a matter of quick decision by the operating men on duty, as prompt action is essential. The situation must be recognized instantly and the correct operations performed in proper sequence without delay. This requires fast thinking and correct action. In most cases the record of the operating men of the large public utilities throughout the country in emergencies is outstanding.

In large systems the problem of overhauling the larger machines becomes quite important. The working out of overhauling schedules that will permit the principal machines to be taken out of service long enough to make any repairs that are required and still carry sufficient reserve on the system during the overhauling period is quite difficult. We have found that with the best overhauling schedules we can work out, the margin of reserve is less in the summer than it is in the winter, as the difference between the winter load and the summer load is now less than the minimum capacity of the machines out for overhauling.

The entire subject of this talk is so broad that it has been impossible to go into very great detail and a complete discussion of any one of the problems involved would be a subject by itself. However, a bird's-eye view of this broad field of the utility business, as outlined in this discussion, shows that the work of the engineers of the industry is a constant challenge to interest, enthusiasm, and ingenuity.

AT RIGHT: Detail Study in Light and Shade. This photograph dramatically presents a portion of a large mine hoist, built for installation in the mill house of a Canadian silver mine.



# MOTOR DRIVES FOR JAW CRUSHERS

• J. Furlong, Assistant Manager

MINING MACHINERY DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

• The jaw type crusher as used for the reduction in size of ores, rocks, stone, etc., is an old invention and probably one of the earliest and most popular crushers. It was patented in 1858 by Eli Whitney Blake and is known everywhere as the Blake Crusher.

The crushing operation is carried out by a forward and receding motion of the swing jaw, which is pivoted at the top and actuated by a toggle from a pitman that in turn is mounted upon the driving shaft. This shaft is provided with an eccentric revolving in the upper bearing of the pitman and causing it to rise and fall. This movement translated through the toggles causes the jaw movement that crushes the material.

There are many modifications of the Blake Crusher, but they are all more or less the same in operating principle. These machines are designated in size by the width and length of the top opening of the jaws where the feed enters. The sizes range from 4 by 1½ to 84 by 66 (all sizes in inches). The power required varies from 1 to 400 hp, and for a given size machine may vary as much as 100 per cent or more depending on the character of the material handled, size of product desired, and capacity.

## • Power input

The power input required for a machine of given size also varies greatly according to the manner of operation and variation in size of material entering the machine, as well as the percentage of fines contained therein and the regularity of the feeder. To compensate partially for these variables, crushers of this type are always provided with flywheels to even out the speed, and they have integral counterweights to compensate for the eccentricity in the pitman. These wheels, however, must not be of too great $WR^2$ value, or the machine might be damaged if stalled by a piece of steel in the material being crushed.

Although attempts are made to make the power input uniform, there is a great variation in the power input as indicated by recording wattmeter charts. A typical curve for a 24 by 15 crusher driven by a 35 hp motor shows:

Running empty — 16 to 17 hp.

Large rocks up to maximum size crusher will take — 35 hp.

Fines filling jaws—40 to 45 hp for as much as two minutes.

Maximum power indicated — 80 to 100 hp, for possibly one second.

Average — 32 hp.

Another example, a 60 by 48 crusher driven by a 200 hp wound rotor motor, shows:

Starting and getting up to speed in 8 minutes — 200 hp.

After starting and running without load — 85 hp.

Power input varying from 80 to 400 hp with an average of 32 readings — 208 hp.

Crushers of this type are started empty, that is, without any rock in the machine. In case of power failure there is enough energy in the flywheels to continue the crusher in motion long enough to free it of rock.

Cases are known where a crusher loaded with rock has been started without being first freed of the rock contained in it, but this is most unusual. Ordinarily if a crusher gets filled up while it is not operating, good practice requires that the rock be removed before the motor is started.

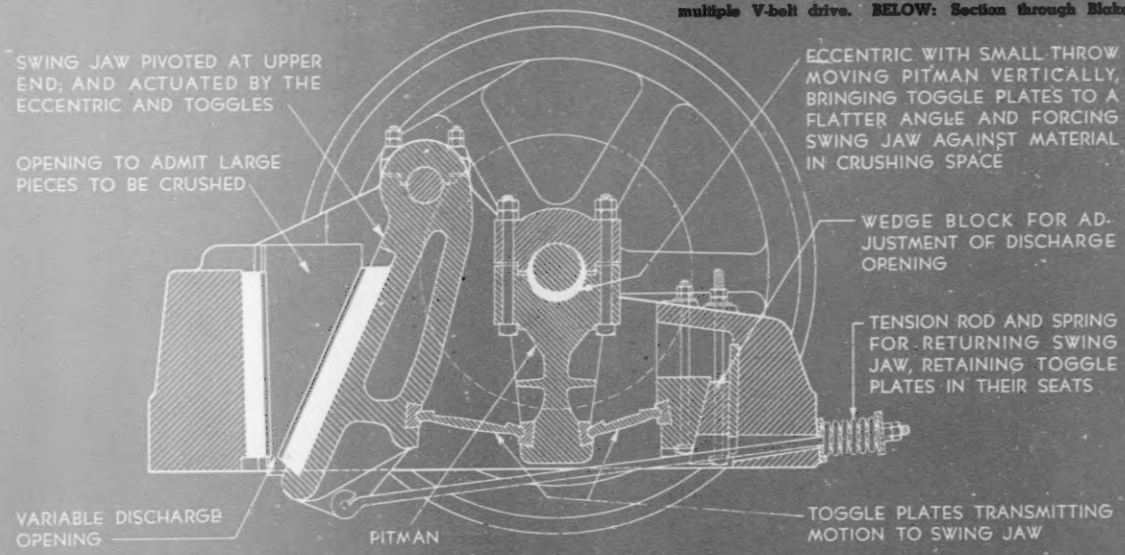
Most crushers of this type are driven by flat belts, "V" belts, or manila ropes. Multiple "V" belt drives are used in the majority of installations.

## • Types of drive

Squirrel cage, wound rotor, or synchronous motors may be used for driving jaw crushers. The type of motor to be used should be carefully considered in each case with due regard for the source of power and the size of the power system supplying the crusher.

Smaller crushers requiring up to and including 75 hp may be driven by squirrel cage type motors with high starting torque where the power conditions do not limit the momentary rush of current in starting. The starting current of a squirrel cage motor is approximately 550 per cent of the full load kva rating of the motor, and since this inrush of current may be objectionable to the power com-

**ABOVE: Superior Jaw Crusher, 84" x 66", manganese fitted, with extra heavy side frames and one flywheel grooved for multiple V-belt drive. BELOW: Section through Blake Crusher.**


SWING JAW PIVOTED AT UPPER END; AND ACTUATED BY THE ECCENTRIC AND TOGGLES
OPENING TO ADMIT LARGE PIECES TO BE CRUSHED
ECCENTRIC WITH SMALL THROW MOVING PITMAN VERTICALLY, BRINGING TOGGLE PLATES TO A FLATTER ANGLE AND FORCING SWING JAW AGAINST MATERIAL IN CRUSHING SPACE
WEDGE BLOCK FOR ADJUSTMENT OF DISCHARGE OPENING
TENSION ROD AND SPRING FOR RETURNING SWING JAW, RETAINING TOGGLE PLATES IN THEIR SEATS
VARIABLE DISCHARGE OPENING
PITMAN
TOGGLE PLATES TRANSMITTING MOTION TO SWING JAW

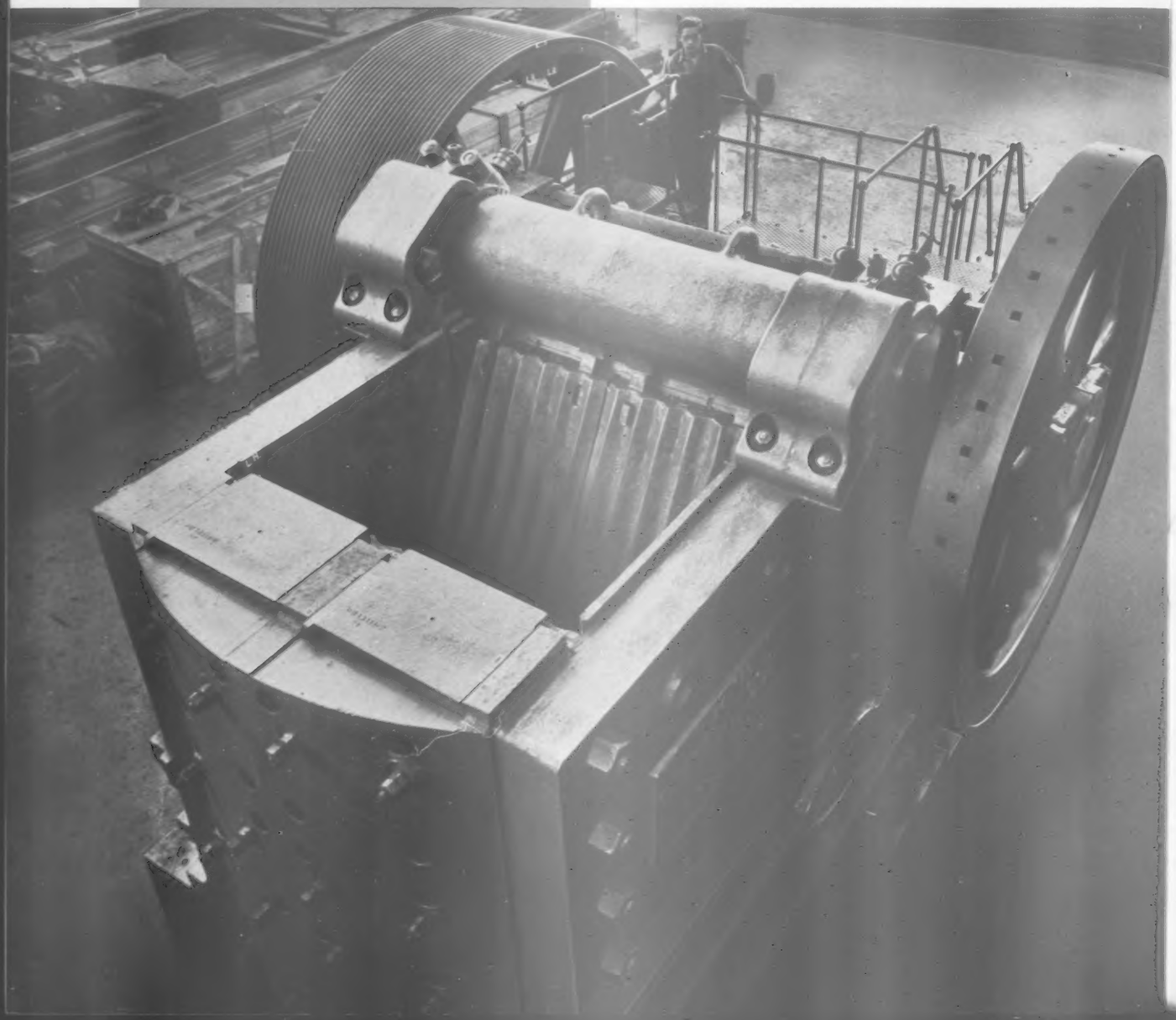
pany it may be necessary to use a wound rotor motor. Wound rotor motors are used in the great majority of cases for all sizes because of the large starting torque available and moderate current demand from the power circuit. Synchronous motors have been used in comparatively few installations for driving crushers, because the conditions of the average installation are not favorable to their use. Crushers are operated intermittently, and the loads are not constant. The advantage of power factor correction can usually be obtained under better conditions by utilizing synchronous motors for other machines in the plant where operation is more continuous.

BELOW: Another view of the all-steel Superior Jaw Crusher, 84" x 66", with extra heavy side frames and one flywheel grooved for multiple V-belt drive, for a large crushing plant.

## • Selection of starters

The selection of starters for the different motors should be given careful consideration as well. For squirrel cage motors, as well as for synchronous motors, it is customary to use across-the-line magnetic starters. For wound rotor motors secondary drum control with resistors are used. The resistors selected should have ample current carrying capacity. The motor and circuit breaker overload should be good for at least 250 per cent of normal rating to avoid tripping out too frequently because of crushing peaks.

It is seen, therefore, that a jaw crusher constitutes an extremely variable torque load, which materially affects the choice of motor. Likewise, the characteristics of the motor selected and the limitations of the line should be considered in selecting the starter.



# SYMMETRICAL COMPONENTS SIMPLIFIED*

• W. C. Sealey
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

In applying symmetrical components to the solution of electrical circuits, the general principles are the same as for the solution without symmetrical components. Symmetrical components should be considered as merely an additional tool in the solution, to be used not in place of but in addition to the usual tools. As such they should be used with discrimination, not as a universal gadget for all purposes. While symmetrical components may be applied to almost any problem, there are certain classes of problems which are greatly simplified by their use. For certain other problems, no simplification is obtained. In fact, their use may unduly complicate the solution. One class of problems in which the use of symmetrical components results in great advantage is in cases where the positive, negative, and zero sequence impedances of the circuit are not the same.

The use of symmetrical components may involve methods of different degrees of complexity. The most direct solutions will be given here. The more complicated solutions may show to advantage when a great number of similar problems require solution. However, the use of the more complicated methods is seldom necessary. These more complicated methods are generally not fundamentally different methods but modifications to provide short cuts which save time but require more attention to their application.

In the general use of symmetrical components the best practice is to solve the problem for the general case, using literal quantities, and then to substitute for the numerical solution.

The method of solution for typical problems will be given in detail for ease in following. If a record of general solutions is kept, it will not be necessary to derive the formula again when a similar problem occurs.

## • Common method of solution

The common method of solution is to consider the circuits three times — once with currents of only positive sequence, once with only negative sequence, and once with only zero sequence flowing. These solutions are then combined to find the resultant voltage and current relations, which of course are the actual voltage and current relations. The division of currents into components should be considered as only a method of solution, since the division is only one arbitrary division out of an infinite number of arbitrary divisions which could be correctly assumed.

An example showing an application of symmetrical components to a typical problem follows:

## • Example No. 1

GIVEN: A 3-phase line (Fig. 16a) with balanced voltages maintained at 2300 volts to neutral at the transformer terminals M.

The current in phase A is 100 amperes at 80 per cent power factor lagging with respect to the voltage to neutral.

The current in phase B is 50 amperes at 100 per cent power factor with respect to the voltage to neutral.

The current in phase C is 150 amperes at 60 per cent lagging power factor with respect to the voltage to neutral.

The positive and negative sequence inductive reactance between the transformer and the load in each line is 2 ohms. The zero sequence inductive reactance in each line is 7 ohms. The resistance of each line is negligible.

REQUIRED: The voltages at the load.

**Solution:** The quantities of total resultant voltages and currents have been indicated by letters in Figure 16.

Let $Z_1$ = the positive and negative sequence impedance in each line.

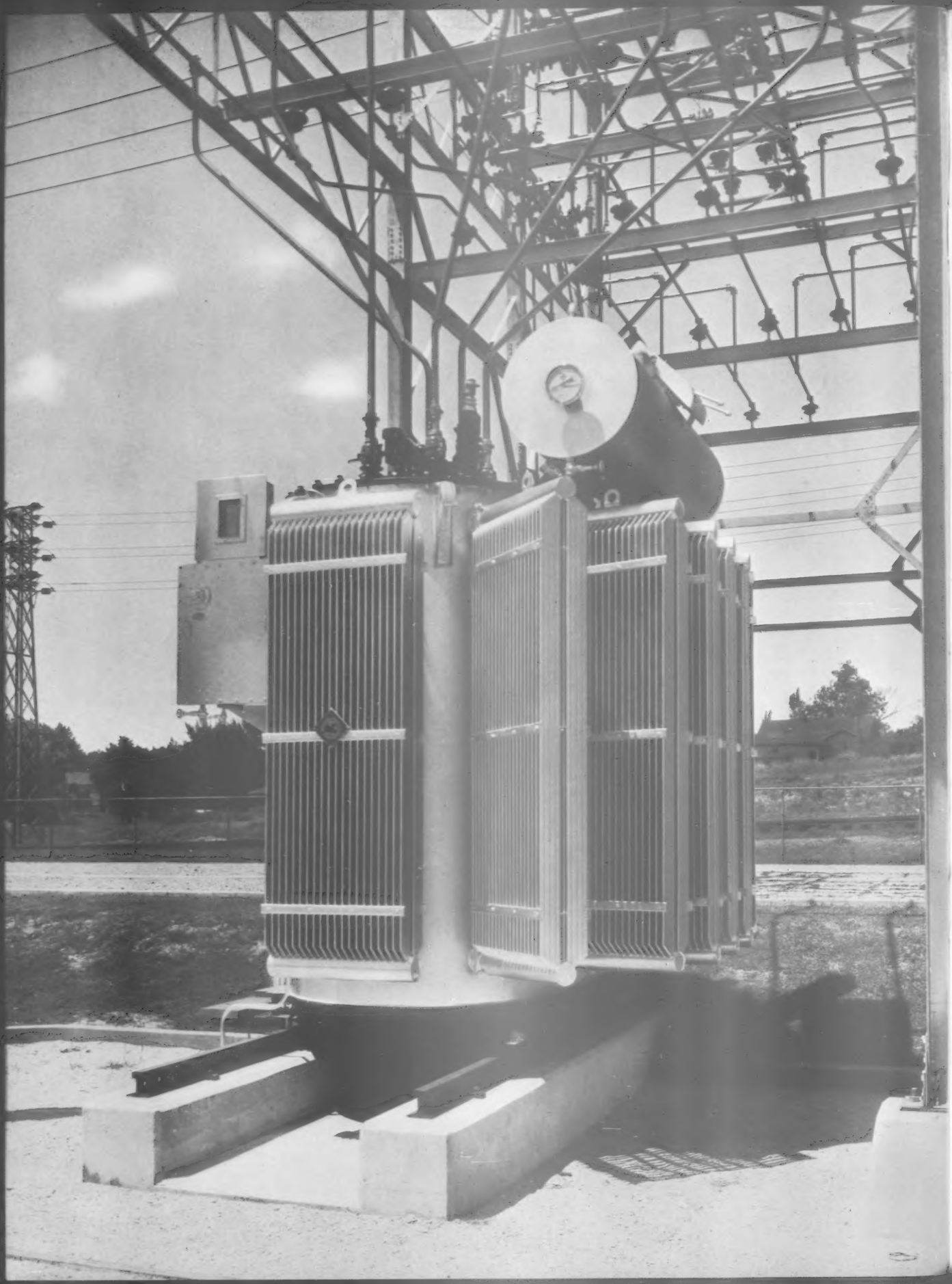
Let $Z_0$ = the zero sequence impedance in each line.

A, B, and C are the three line currents in lines A, B, and C respectively.

$A_0$ is the zero sequence current.

$A_1$, $B_1$, and $C_1$ are the positive sequence components of current in lines A, B, and C respectively.

* See "Symmetrical Components Simplified," by W. C. Sealey, Allis-Chalmers Electrical Review, Dec., 1936.



$A_2$, $B_2$, and $C_2$ are the negative sequence components of current in lines A, B, and C respectively.

As given in a previous article*

$$B_1 = a^2 A_1$$
$$C_1 = a A_1$$
$$B_2 = a A_2$$
$$C_2 = a^2 A_2$$

Where $a = -.5 + j.866$
and $a^2 = -.5 - j.866$

The following relations can be set up by referring to Figure 16, considering the voltage drop due to each component separately.

The voltage drops from M to G in phase A are:

1. Referring to Fig. 16(c) and considering the zero sequence current only, $A_0 Z_0$
2. Referring to Fig. 16(b) and considering the positive sequence current only, $A_1 Z_1$
3. Referring to Fig. 16(b) and considering the negative sequence current only, $A_2 Z_1$

The total voltage drop from M to G in phase A is the sum of the voltage drops due to the three components, or $A_0 Z_0 + A_1 Z_1 + A_2 Z_1$.

The voltage $E_d$ is equal to the voltage $E_a$ minus the voltage drop from M to G in phase A, that is,

(1) $E_d = E_a - A_0 Z_0 - A_1 Z_1 - A_2 Z_1$
$= E_a - A_0 Z_0 - (A_1 + A_2) Z_1.$

Similarly, for phase B,

(2) $E_e = E_b - A_0 Z_0 - B_1 Z_1 - B_2 Z_1$
$= E_b - A_0 Z_0 - (B_1 + B_2) Z_1.$

And for phase C,

(3) $E_f = E_c - A_0 Z_0 - C_1 Z_1 - C_2 Z_1$
$= E_c - A_0 Z_0 - (C_1 + C_2) Z_1.$

Note that the current in line A is the sum of $A_0$, $A_1$ and $A_2$; the current in line B is the sum of $A_0$, $B_1$ and $B_2$; the current in line C is the sum of $A_0$, $C_1$ and $C_2$.

If $E_a$ is arbitrarily selected as the reference vector,

$$E_a = 2300$$
$$E_b = 2300\ (-.5 - j.866) = -1150 - j1992$$
$$E_c = 2300\ (-.5 + j.866) = -1150 + j1992$$

From the data for the currents,

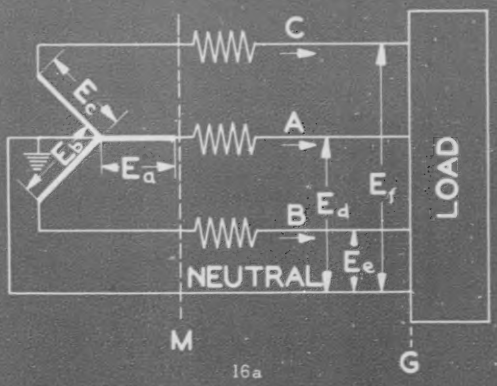
$$A = 100\ (.8 - j.6) = 80 - j60$$
$$B = 50\ (-.5 - j.866) = -25 - j43.3$$
$$C = 150\ (.393 + j.920) = 59 + j138$$

The sequence components $A_0$, $A_1$, and $A_2$ are derived from the equations previously given as follows:

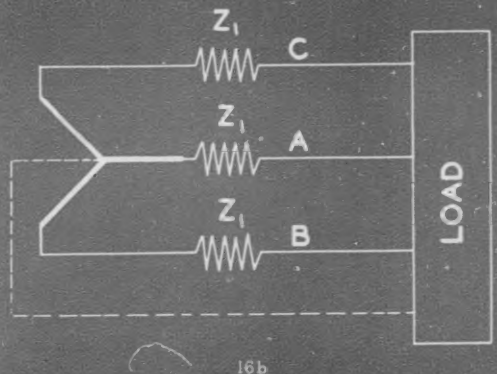
$$A_0 = \tfrac{1}{3}\ (A + B + C) = \tfrac{1}{3}\ (80 - j60 - 25 - j43.3 + 59 + j138)$$
$$A_0 = 38 + j11.6$$

* "Symmetrical Components Simplified," by W. C. Sealey, Allis-Chalmers Electrical Review, Dec., 1936.

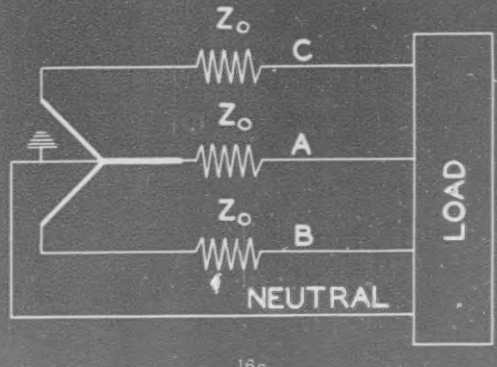
AT LEFT: Regulating transformer, 30,000 kva. 3 phase, to produce ± 7½% regulation in thirty-two steps under load on a 19,800 volt line of a large southern utility company.




16a




16b




16c

FIGURE 16

$A_1 = \frac{1}{3}(A + aB + a^2C) = \frac{1}{3}$ [80—j60+(—.5+j.866) (—25—j43.3)+(—.5—j.866) (59+j138)]

$A_1 = 73.3 - j60$

$A_2 = \frac{1}{3}(A + a^2B + aC) = \frac{1}{3}$ [80—j60+(—.5—j.866) (—25—j43.3)+(—.5+j 866) (59+j138)]

$A_2 = -31.3 - j11.5$
$A_1 + A_2 = 42 - j71.5$
$B_1 = a^2A_1 = (-.5 - j.866)\ (73.3 - j60) = -88.6 - j33.5$
$C_1 = aA_1 = (-.5 + j.866)\ (73.3 - j60) = 15.4 + j93.5$
$B_2 = aA_2 = (-.5 + j.866)\ (-31.3 - j11.5) = 25.5 - j21.4$
$C_2 = a^2A_2 = (-.5 - j.866)\ (-31.3 - j11.5) = 5.7 + j32.8$
$B_1 + B_2 = -63.1 - j54.9$
$C_1 + C_2 = 21.1 + j126.3$

Substituting these values in the derived equations (1), (2), and (3):

$E_a = E_a - A_0 Z_0 - (A_1 + A_2) Z_1 = 2300 - (38 + j11.6)\ (j7) - (42 - j71.5)\ (j2)$

$E_a = 2300 - (62 + j350) = 2238 - j350$

$E_a = \sqrt{2238^2 + 350^2} = 2260$ volts

$E_b = E_b - A_0 Z_0 - (B_1 + B_2) Z_1 = -1150 - j1992 - (38 + j11.6)\ (j7) - (-63.1 - j54.9)\ (j2)$

$E_b = -1150 - j1992 - (29 + j140) = -1179 - j2132$

$E_b = \sqrt{1179^2 + 2132^2} = 2440$ volts

$E_c = E_c - A_0 Z_0 - (C_1 + C_2) Z_1 = -1150 + j1992 - (38 + j11.6)\ (j7) - (21.1 + j126.3)\ (j2)$

$E_c = -1150 + j1992 - (-334 + j308) = -816 + j1684$

$E_c = \sqrt{816^2 + 1684^2} = 1870$ volts

In this problem the zero sequence impedance is different from the positive and negative sequence impedances, and there is zero sequence current flowing in the circuit. If the zero sequence current were equal to zero, the solution would be simpler if the currents were not resolved into their symmetrical components. However, when the zero sequence components are present, the solution is greatly simplified by the use of symmetrical components.

## • Complete solution

The complete solution including the substitution of numerical values is given to illustrate the complete method. Most practical cases require a similar substitution of numerical values after the literal solution has been obtained.

## • Example No. 2

GIVEN: The circuit of Fig. 16(a) with voltage maintained as before but with no load on the circuit and a short circuit at point G between line A and ground.

REQUIRED: The short circuit currents in the circuits.

**Solution:** The solution is obtained by reference to the equivalent circuits of Figures 16(a), 16(b), and 16(c). By referring to these figures, equations expressing the circuit relations are set up and solved simultaneously to obtain the desired values. The equations set up are the general equations of (1), (2), and (3). In these equations, since there is a short circuit to ground at G, on line A, $E_a = 0$

Since no current flows in the line B or C, $B = 0$ and $C = 0$

(4) $E_a = E_a - A_0 Z_0 - (A_1 + A_2) Z_1 = 0$ from equation (1)

(5) $B = A_0 + B_1 + B_2 = A_0 + a^2A_1 + aA_2 = 0$

(6) $C = A_0 + C_1 + C_2 = A_0 + aA_1 + a^2A_2 = 0$

(7) From (5) and (6), $a^2A_1 + aA_2 - aA_1 - a^2A_2 = 0$
$A_1\ (a^2 - a) = A_2\ (a^2 - a)$

(8) $A_1 = A_2$

From (5) and (8), $A_0 + a^2A_1 + aA_1 = 0$
$A_0 + A_1\ (a^2 + a) = 0$
but $a^2 + a = -1$

(9) $A_0 = A_1$

From (4), (8), and (9): $E_a - A_0 Z_0 - 2A_0 Z_1 = 0$

Solving for $A_0$, $A_0 = \frac{E_a}{Z_0 + 2Z_1} = A_1 = A_2$

$$A = A_0 + A_1 + A_2 = 3A_0 = \frac{3E_a}{Z_0 + 2Z_1}$$

$E_a = 2300$ volts
$Z_0 = j7$ ohms
$Z_1 = j2$ ohms

$$A = \frac{3 \times 2300}{j(7 + 2 \times 2)} = \frac{6900}{j11} = -j627$$

The current in line A = 627 amperes. By inspection of the circuits, the neutral current is equal to the current in line A, or 627 amperes. The current in the other lines equals zero.

For other circuit conditions the solution can be obtained in similar fashion. The general method is always the same. The simplest procedure is to solve the circuits using letters to represent the various quantities instead of numerical values. To keep the procedure simple, the currents only are divided into their symmetrical components. (In general, the solution is not appreciably simplified by dividing the voltages into their symmetrical components.) The known circuit relations are then expressed in equations in terms of letters representing the symmetrical component currents and letters representing the voltages and impedances. The equations are set up using the conditions of the problem and the well-known laws of the electrical circuit. These equations are solved simultaneously to determine the desired quantities. This direct method of solution is effective for practically all problems where the use of symmetrical components is necessary or desirable.



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